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Development and Validation of a Mobile, Autonomous, Broadband Passive Acoustic Monitoring System for Marine Mammals

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LONG-TERM GOALS

Our long-range objective is to understand the oceanographic processes that influence the distribution of whales in the ocean. In support of this objective we are developing a fully-integrated autonomous acoustic observing system capable of detecting and classifying a wide range of marine mammal vocalizations (from blue whales to beaked whales; 10 Hz – 100 kHz) with proven performance. This work will ultimately improve our ability to predict whale distribution and bolster efforts to mitigate human impacts on marine mammals. High-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.

APPROACH

High-endurance autonomous platforms have tremendous potential for persistent monitoring of the ocean environment, including ambient noise and marine mammal vocalizations. We have previously demonstrated the utility of such platforms by simultaneously collecting passive acoustic recordings, environmental measurements, and prey observations from a fleet of ocean gliders. In contrast to these studies, which resulted in recorded audio data that were analyzed weeks after collection, many applications require almost immediate data return to facilitate at-sea decision making. To meet this

need, the autonomous platform must be able to acquire and rapidly process acoustic data on board, detect and classify vocalizations, and telemeter a useful summary of those detections to a ship- or shore-based station.

There is a wide variety of instrumentation and software available for collecting and analyzing marine acoustic data; however, most existing tools are optimized for either low or high frequency applications. While this is acceptable for researchers focusing on particular taxa, most conservation and mitigation efforts must address the needs of a broad range of species. For example, some species of beaked whales may be especially sensitive to active sonar while certain baleen whales are at risk from ship strikes, yet there is no single instrument capable of monitoring both taxa simultaneously from a variety of autonomous platforms (gliders, floats, drifters, moorings). We have therefore developed a low-power digital monitoring instrument that is capable of long-term autonomous detection and classification of vocalizations over the frequency range encompassing most marine mammals.

Our observing system is based on a new self-contained, low-power digital acoustic monitoring device (DMON) developed at WHOI by co-PI Mark Johnson. Under support of this program we have integrated the DMON in commercially-available gliders, profiling floats, and surface drifters to create a fleet of persistent real-time acoustic monitoring platforms. In parallel, we have developed acoustic detection and classification algorithms to identify two critical classes of marine mammals: low-frequency baleen whales (e.g., right, fin, humpback whales), and high-frequency beaked whales. The performance of these detectors will be verified at several field sites with the opportunity for independent ground-truth. The work has resulted in a modular, open-source, acoustic detector capable of installation on a wide variety of autonomous platforms, together with an understanding of how to use these platforms to maximize detection performance in fleet-relevant monitoring tasks.

This project encompassed three major efforts: detector design, hardware and software implementation, and field verification.

Detector design: Successful detector design requires a knowledge not only of the properties of the signals to be detected but also of the environment and behavior of the animals that produce them. Our approach is an integrated one in which detector design is directly informed by observations from on-going field studies. This focuses attention on the real conditions in which an autonomous detector has to operate, e.g., fluctuating ambient noise and frequent interference from non-target species. We are thus creating detection methods that are robust, extensible and verifiable from the outset.

Implementation: Detector algorithms will be implemented in real-time on the DMON, a low-power self-contained acoustic signal processing device developed at WHOI. This device has been created specifically for passive acoustic detection and so has the necessary broadband, low-noise signal acquisition capabilities. The device will be integrated in profiling floats and gliders to create a persistent detection capability. As detection algorithms mature, they will be ported to the DMON for autonomous operation. It is our desire that all elements of the DMON design be made openly available to the community under a share-alike license. This ensures that new developments do not remain proprietary will still providing recognition for contributions. We believe that this open approach is the best and most efficient way to obtain community-accepted, verifiable and inter-operable methods for passive acoustic monitoring. Initially, DMONs will be fabricated at WHOI and will be an orderable item. If sufficient orders are received, production will be transitioned to a turn-key contractor in the short-term and we will seek an alliance with an oceanographic instrument producer in the long-term.

Verification: Our detectors will be verified in two ways. First, signals from known species recorded in the field will be used for bench verification of algorithms and implementations. Complete autonomous systems will then be tested in the field using DMON to simultaneously detect and record sound. This allows performance and missed detects to be evaluated after each trial. For beaked whales, field testing will take place off the island of El Hierro in the Canary Islands, a site with coastal resident populations of Blainville's beaked whale, Mesoplodon densirostris, and Cuvier's beaked whale, Ziphius cavirostris. This site is unique in supporting simultaneous visual and acoustic observations of these rare species with low-cost shore-based operations. Baleen whale validation efforts were pursued in the northeastern U.S. in the vicinity of Cape Cod.

WORK COMPLETED

DMON hardware and software: The DMON (Figure 1) is a small self-contained acoustic detector/recorder. The device 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. The three 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 a PAM implementation using off-the-shelf hardware, the DMON design offers several advantages:

(1) power consumption is <10% of what an embedded PC requires for the same computation rate. This translates into longer deployment lifetimes on platforms such as gliders with limited hotel load.

(2) the DMON is specifically designed for low noise sound acquisition. It produces very little electrical noise 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 and non-portable software, and lack of availability to other researchers. We are addressing these issues as follows. We have developed a software infrastructure which provides a familiar programming environment for scientific programmers. The software and hardware design will be openly available and devices will be purchasable at relatively low cost from WHOI. Our vision is that the DMON form a reference design for the rapidly expanding field of passive acoustic monitoring.

Platform modification: Profiling floats are generally expendable. However, we required an ability to recover floats following an experiment in order to access large volumes of audio recordings stored onboard. Six WRC APEX profiling floats were modified with new controllers, new Iridium communications systems, internal mounting brackets for DMON hardware, and ancillary equipment (flags, lanyards, paint) required for easy recovery at sea (Figure 2). The APEX DMON hydrophone assembly (Figure 3) attaches to the float's top end cap. Four WRC Slocum gliders were internally modified to carry a DMON cardset. The Slocum DMON hydrophone assembly (Figure 3) uses a standard through-hull stem design that enables its placement on the, bottom, or sides of a glider.

DMON-Vehicle integration: We have integrated the DMON into two low-power platforms capable of persistent monitoring: the Webb Research Corporation's Slocum glider and APEX profiling float. External hydrophones for both platforms provide 10Hz-60kHz monitoring. Serial communications

with the vehicle controllers allow near-real-time feedback of detections via Iridium. A drifting surface float with a cabled array of DMONs has also been developed to facilitate rapid field evaluation of detection and tracking algorithms. The three platforms provide the capability to work over a wide range of spatial and temporal scales. APEX and Slocum firmware were specially modified to address the DMON hardware. Both platforms are now capable of including DMON detector output in their satellite-telemetered data streams.

Detector/classifier development: We continue to develop 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 (e.g. Baumgartner and Mussoline, 2010). The beaked whale detector incorporates discrimination of dolphin clicks based on spectral and click-rate cues. We are currently porting both detectors for real-time operation on the DMON and are evaluating the detection range of the beaked whale detector using sound recordings made by DMONs of whales tagged with the WHOI DTAG acoustic recording tag (Johnson & Tyack, 2003).

Significant Field Trials (=pending):*

Baleen Whale Studies

Great South Channel, May 2009: 2 DMONs as LF recorders in profiling floats.

Central Gulf of Maine, Nov 2009: 3 DMONs as LF recorders in glider, profiling floats

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

Great South Channel, May 2010: 3 DMONs as LF+MF recorders in gliders.

SCORE Range, Nov 2010: 3 DMONs as LF+MF recorders/detectors in glider, floats. (*)

Beaked Whale Studies

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

Canary Islands, 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 2010: 10 DMONs in MF spatial (vertical and horizontal) drifting arrays.

Almeria, Spain, August 2010: 4 DMONs as MF recorders in drifting buoys

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

RESULTS

We have used the new DMON-equipped gliders and profilers in several field trials with great success. It is premature to report substantial scientific results from these trials. However, we have been able to evaluate the performance of the DMON in record-only mode. The system is low-noise, power- and data-efficient, and reliable. We are continuing (under a related program) to develop and refine detectors, implement them on the DMON, and validate LF and MF detection capabilities using the DMON-equipped platforms.

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, 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.

RELATED PROJECTS

Further refinement of DMON and relevant detectors and broad dissemination of these tools is the topic of "Beta testing of persistent passive acoustic monitors" (N000141010381; PI's Johnson, Fratantoni, Baumgartner). The primary goal of this closely-related program is to produce 20 DMON digital acoustic monitors for distribution to a group of collaborators developing systems for acoustic monitoring of marine mammals and able to evaluate the device and its software in a range of applications. These systems will be targeted for both stand-alone use and integration in various mobile and moored platforms.

The initial development and validation of baleen whale detectors was supported under a companion ONR program "Detection and Classification of Baleen Whale Vocalizations from Autonomous Platforms," completed in 2009. See Baumgartner and Mussoline (2010).

TRANSITIONS

The vehicle-side code required to integrate DMON with the Webb Slocum glider is now contained within the standard WRC glider software package and is publically available. Any user of a Slocum glider has immediate access to this code. Comparable code for the APEX profiler is also available.

PUBLICATIONS

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and DTAG recordings on multiple whales", 4th International Workshop on Detection, Classification and Localization of Marine Mammals using Passive Acoustics, Pavia, Sept. 2009.

Ward, J., Morrissey, R. P., Moretti, D. J., DiMarzio, N., Jarvis, S., Johnson, M., Tyack, P. L., White, C. (2008). "Passive acoustic detection and localization of Mesoplodon densirostris (Blainville's beaked whale) vocalizations using distributed bottom-mounted hydrophones in conjunction with a digital tag (DTAG) recording". Can. Acoust. 36:60-73. [published, refereed]

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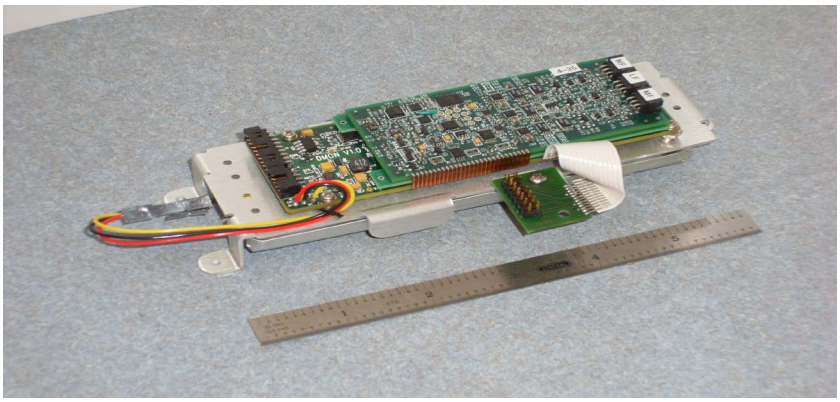

Figure. 1: DMON board set in glider-ready format.
The DMON is a set of two circuit boards capable of wide bandwidth acoustic recording and real-time detection. The device consumes little power making it ideal for low hotel load autonomous vehicles like gliders.

Figure 2: Photo of APEX Profilers with installed DMON and 3-channel hydrophone assembly (top end cap to left of flag). Profilers were modified to enable post-experiment recovery, including addition of Iridium 2-way satellite communications.

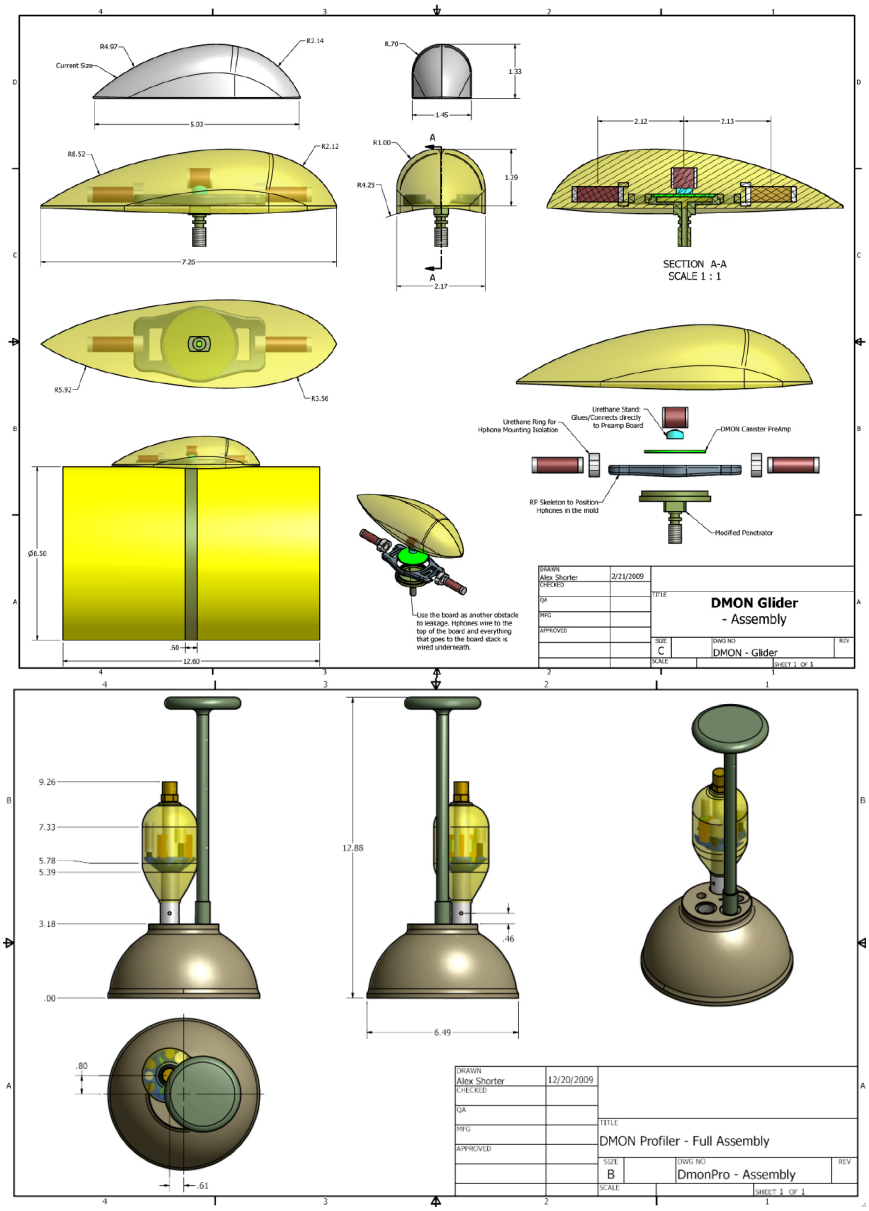

Figure 3: External multi-channel hydrophone assemblies developed for (top) Slocum glider and (bottom) APEX Profiler.