The DMON2: A Commercially Available Broadband Acoustic Monitoring Instrument

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LONG-TERM GOALS

There is currently an urgent need to autonomously record, detect, classify, and report marine mammal calls for both research and mitigation applications. For marine mammal research, such a capability would greatly improve the efficiency of finding animals at sea for study (e.g., for tagging or photo-identification). For the National Oceanic and Atmospheric Administration (NOAA), such a capability would allow improved monitoring of the distribution and occurrence of vocalizing animals for improving our understanding of stock structure and characterizing anthropogenic threats. For both the Navy and some industries that are interested in mitigating their interactions with marine mammals, real-time detection can augment and improve the efficiency of traditional detection methods (e.g., aerial and shipboard surveys), while providing persistent surveillance for marine mammals when traditional methods are ineffective (e.g., at night, during rain, fog, snow, or high winds).

To meet this urgent need, engineers at the Woods Hole Oceanographic Institution developed the digital acoustic monitoring (DMON) instrument, a passive acoustic device capable of recording and processing audio aboard a variety of autonomous platforms. The original DMON (Figure 1) was conceived as an open-design programmable passive acoustic instrument, but in early 2010, the DMON was determined to be a defense article by the U.S. Department of State because its "open architecture software and source code allow users to easily tune the device for other purposes, including submarine detection" (U.S. Department of State Commodity Jurisdiction Determination Letter for the DMON, January 21, 2010). This prevented the use of the DMON outside of U.S. territorial waters without an export license, severely restricting its application. Our long-term goal is to make this very capable instrument available to the broader scientific, governmental, and industrial communities for use in mitigation, science, and conservation applications.

OBJECTIVES

Our objectives are to develop the DMON2, a new version of the DMON that will (1) allow full spectrum (10 Hz to 160 kHz) recording and processing, (2) be exempt from licensing jurisdiction from the Department of State and Department of Commerce, thus allowing international sales and operation, (3) be much easier to manufacture in commercial quantities, and (4) be much easier to maintain both at the manufacturing facility (WHOI) and in the field. We will obtain a new commodity jurisdiction for the DMON2 that will allow it to be used outside of U.S. territorial waters and exported for international purchase and use. We will change the design to accommodate the new commodity jurisdiction as well as to improve manufacturability, maintenance, and performance of the instrument. Upon completion of this project, we will make the DMON2 commercially available to both domestic and international customers using the same business model as the very successful, industry-standard, acoustic communication device, the WHOI Micro-Modem.

APPROACH

The DMON2 hardware components will be identical to those of the current DMON, retaining all of the functionality of the original instrument. Features that are prohibited by the DMON2 commodity jurisdiction (e.g., external synchronization of the real-time clock) will either be hardware or software disabled. In essence, we will manufacture DMON hardware that will be sold to the vast majority of customers as DMON2 instruments after minor proprietary hardware and software modifications are made. The DMON instrument (i.e., the manufactured instrument *without* the modifications) will continue to be available for sale to users with an appropriate export license.

Several changes will be made to satisfy the new commodity jurisdiction. A pressure transducer will be included in the hydrophone head so that the transducer output can be disabled when the system exceeds 1000 m depth. The external PPS timing circuit will be disabled; thus the instrument's real-time clock cannot be externally synchronized, and it cannot therefore be configured in arrays. Finally, only authorized firmware will be allowed to run on the DMON2; the instrument will not be programmable.

Changes will be made to the design to allow the DMON2 to be much simpler to build and easier to maintain. These changes will not add significantly to the overall size and weight of the device, but are economically essential to making the DMON2 commercially available. We will develop and use a standard, non-oil-filled pressure housing to allow easy and quick access to the card set, internal battery, and hydrophones. We will also make several changes to improve assembly and maintenance, including a modular circuit board design and simpler, more reliable connectors. These changes will make the DMON2 easier to build and bench test (reducing assembly costs) and they will enable field replacement of defective components by the user. The memory capacity will be increased from 32 GB to 128 GB, with the option to include an additional memory board with even more flash memory. The internal battery capacity will be increased from 5 to 10 A-hr to allow for longer deployments.

The following is a summary of the DMON2 design:

- Overall concept (system level design):
    - Adoption of a two component system: (1) Main electronics and battery housing and (2) modular (detached) transducer head.
    - Manufacturability, ease of assembly/service, reduced cost and export classification all contributed to the need for a new system design.
    - Seamless integration of the DMON2 with multiple platforms: Slocum and Wave Gliders, moored real-time buoys and bottom-mounted moorings.

- Main electronics and battery housing (system level):
  - Use a standard pressure housing with a single end cap for external connections.
  - Combine existing Main and Audio printed circuit boards into a single board design.
  - Retain rechargeable lithium polymer for standard operations (increase capacity for longer operations)
  - Accommodate add-on battery inside the pressure housing for extended operations.
  - Accommodate an additional circuit board with added flash memory.
- Transducer head (system level):
  - Adoption of a modular 3-hydrophone (low-, mid-, and high-frequency) design.
  - Add an analog pressure sensor, LEDs, EEPROM, and serial (I2C) communications.
  - Identify a suitable pressure transducer that will operate when encapsulated in urethane.

WORK COMPLETED

Since the inception of the project, the following tasks have been accomplished:

- Consultation with the Naval Undersea Warfare Center (NUWC) on the new DMON2 design specifications in preparation for our commodity jurisdiction request to the Department of State.
- Submission of commodity jurisdiction request to the Department of State (March 17, 2014).
- Determination that the DMON2 is not subject to the jurisdiction of the Department of State (June 17, 2014).
- Assignment of Export Control Classification Number (ECCN) of 6A991 by the Department of Commerce for the DMON2 (July 30, 2014), allowing the DMON2 to be exported.
- Design of new DMON2 main board underway. Detailed design specifications nearly finalized.
- Schematic design of modular 3-hydrophone (low-, mid-, and high-frequency) head finalized; mechanical drawings nearly finalized.
- Design of new housing underway. Currently iterating on minimum outside diameter of pressure housing given main DMON2 board dimensions and available OEM battery packs (both alkaline and lithium primary). Housing will be compatible for use on Slocum gliders, Wave Gliders, moored real-time buoys, and bottom-mounted moorings.

RESULTS

Our commodity jurisdiction requests were successful and the DMON2 is now non-ITAR and fully exportable. This ensures that it can be used outside of U.S. territorial waters without an export license and that it can be sold to and used by international customers. The convenience of this even for U.S. researchers cannot be understated.

System Level Design

We have revisited all elements of the original DMON system design to make it more robust, manufacturable, maintainable, debuggable, and expandable, while maintaining its acoustic performance, low-power operation, and compact size, as well as supporting the export classification requirements. All the elements of the overall system design are being iteratively co-designed, due to their system level interactions (e.g., the circuit board power consumption determines the battery pack sizes, which in turn drive the mechanical housing dimensions).

To maintain flexibility across platforms, support future expandability and ease manufacturing and service costs, we have decided on a two-component system for the DMON2: (1) an electronics and battery housing and (2) modular transducer head.

Main Electronics and Housing

We are designing a standard aluminum pressure housing for the DMON2, in contrast to the original DMON's oil-filled urethane housing. Using a standard housing will greatly reduce assembly and maintenance costs. It will also improve robustness for long deployments, and will allow for basic field maintenance by end users (e.g., to swap battery packs for a quick turnaround between long deployments).

All external connections to the DMON2 have been moved to a single endcap. This will accommodate wet pluggable connectors for the transducer head interface, USB interface and external power and communications. This will allow all of the electronics connections to be easily accessible simply by removing the pressure housing. Assembly, testing and field service from this single access point will be simple and take very little time. In addition, the new pressure housing will easily and inexpensively allow for expandable internal battery packs, supporting deployments of up to 1 year.

We have decided to combine the Main and Audio electronics (formerly residing on two different boards in the original DMON) into a single board and are in the process of finalizing this new design. This will substantially reduce production and assembly costs, since the original DMON's two circuit boards required time-consuming and expensive hand assembly by skilled technicians. Combining the original DMON's two circuit boards into one board will also allow space for a second optional circuit board that we plan to use for memory expansion. We are currently researching the addition of a memory circuit board with ~1TB of low-power NAND flash memory. This additional memory will support both high-frequency and long-duration sampling beyond that supported by the standard 128GB available on the DMON2 Main board, while using less power than SD cards and much less than solid-state drives. The DMON and DMON2 both use lossless compression with a typical compression ratio of approximately 3×, extending the storage capacity beyond similarly-specified recording systems that do not employ compression (note that the lossless compression does not assume any pyschoacoustic model of human hearing, as do most lossy audio compression algorithms).

Transducer head

We have designed a small modular transducer head that integrates 3 hydrophones (low-, mid-, and high-frequency), preamplifiers, EEPROM (for storing hydrophone calibration constants), a pressure sensor, and LEDs. The existing low power, low noise audio circuitry of the original DMON has been retained in this new design. The head will be encased in acoustically transparent urethane and it will connect to the DMON2 via a short cable. The cabled connection will allow the low-mass hydrophone head to be shock-mounted and mechanically decoupled from the platform, which is critical for platforms with impulsive motion such as a Wave Glider. We have completed the revised schematic circuit design for the transducer head.

The ECCN 6A991 classification requires that an external pressure transducer be mounted in the head so that the hydrophone output can be disabled below 1000 m. We tested whether a pressure transducer would operate as expected while encapsulated in urethane, and whether it could hold its calibration over many pressure cycles. Two Keller pressure transducers were identified for testing: PA3L and Series 1 TAB, both previously used in DMON and DTAG designs. The transducers were potted in Conap Conathane 401 urethane (Figure 2) and pressure cycled in the WHOI pressure chamber (Figure 3). After over 600 hours of testing and about 500 cycles, both transducers were deemed suitable. The PA3L was determined to be a better option given ease of assembly and robustness (stainless steel design).

IMPACT/APPLICATIONS

The Navy regularly conducts studies to monitor marine mammal distribution and occurrence in association with training exercises to better mitigate interactions between marine mammals and naval activities. Real-time detection from autonomous platforms can augment traditional visual surveys to greatly improve efficiency and planning. ONR has supported the development of the DMON instrument to achieve these improvements, but it cannot be widely used until it is made available commercially. The technology has been sufficiently tested and demonstrated, and it is now ready to be transitioned to much broader use. This project will facilitate this transition by creating an extremely functional version of the DMON that can be used without an export license and by improving manufacturability and performance.

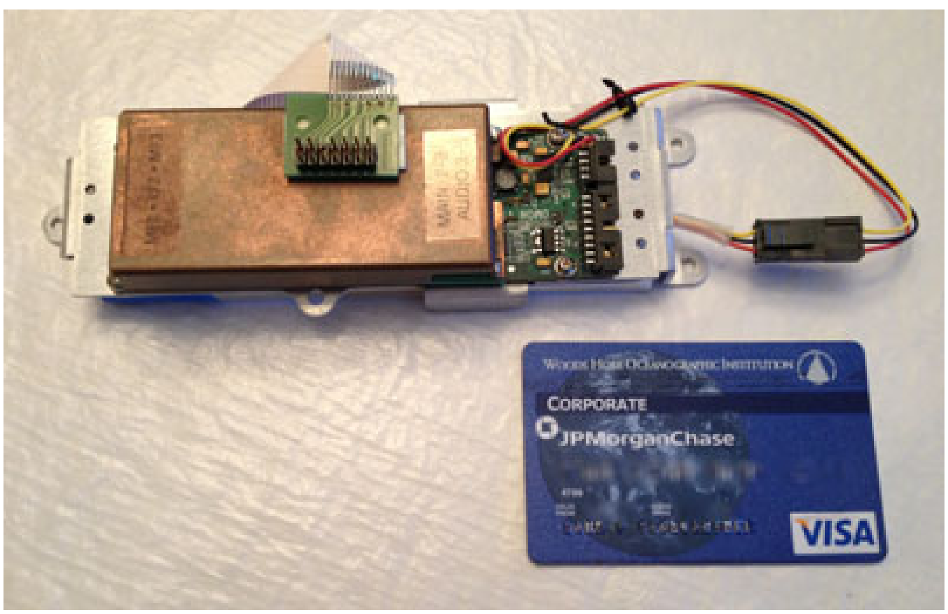

Figure 1. Digital acoustic monitoring (DMON) instrument.
Credit card included for size comparison.

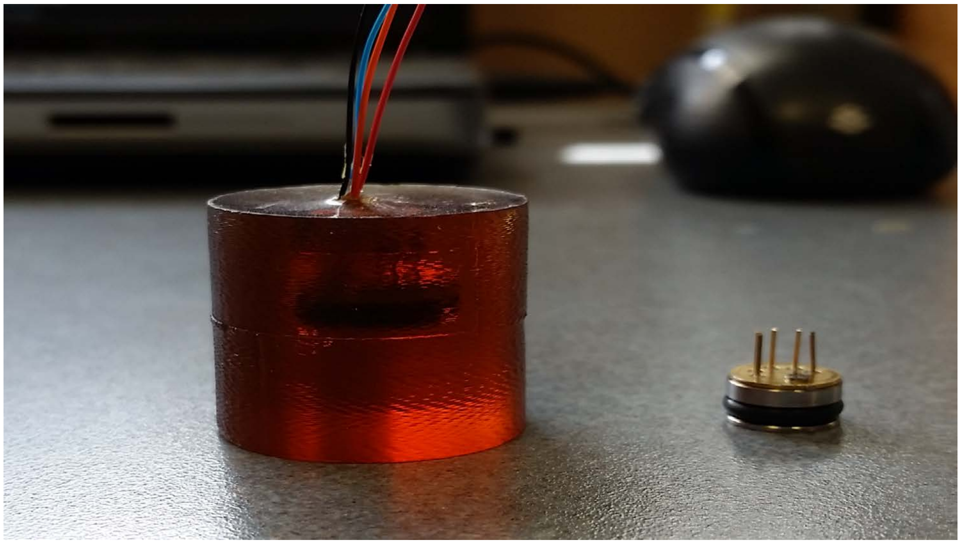

Figure 2. Keller PA3L pressure transducer (right) encapsulated in urethane (left) for pressure sensor tests.

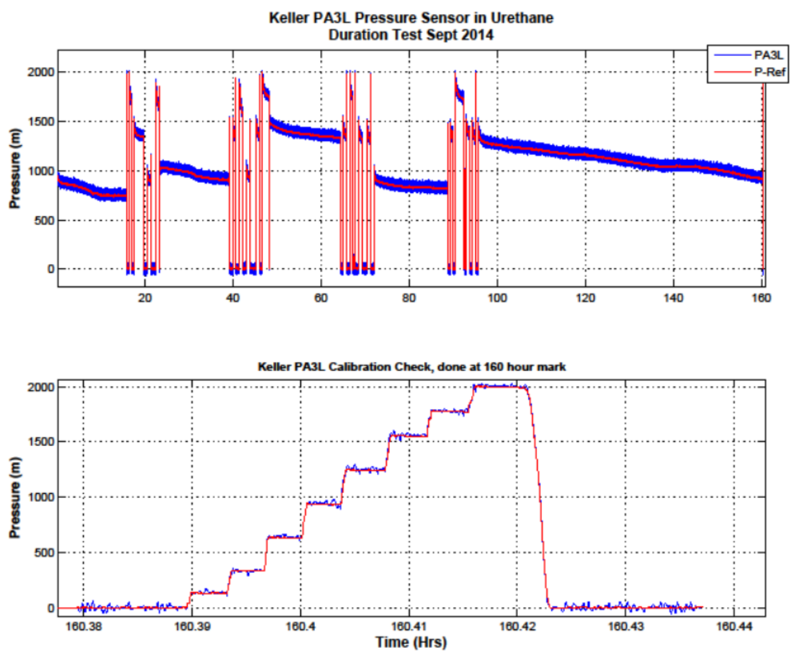

Figure 3. Pressure cycling of Keller PA3L transducer during testing (blue) compared to Measurement Specialties Inc. MSP-600-5K reference transducer (red)