# Multi-Channel Acoustic Data Acquisition and Telemetry on an Autonomous Vehicle for Marine Mammal Monitoring

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**Abstract — The impact of anthropogenic noise on marine mammals is becoming an increasingly important area of study for regulatory and research purposes. To assess these impacts, archival underwater acoustic recorders are typically deployed before the activity of interest, then retrieved and their data analyzed afterwards. The significant drawback to this approach is that impacts can only be assessed well after the activity in question, making mitigation of that particular activity impossible. A more recent technology developed to reduce the probability of whale-ship collisions, the Auto-Buoy system [1], reduces the time between activity and mitigation with a delay of 20-30 minutes, but does not address noise impacts. Recent interest in using the Wave Glider® (Liquid Robotics, Sunnyvale, CA) for environmental monitoring related to the oil and gas industry [2], and using it to acquire acoustic data [3-5], suggests the potential for using this autonomous vehicle as a real-time monitoring and mitigation tool. The current work involves developing an acoustic data acquisition and transmission system for use with a Wave Glider, to provide real-time data for marine mammal monitoring and mitigation [6]. The goal of the system is to be capable of persistent, autonomous, real-time monitoring of marine mammals in areas that would otherwise not be surveyed, as it will not require a local ship for its deployment, its retrieval, or reception of data for human review.**

***Keywords - marine mammal; monitoring; acoustics; detection; hydrophone; AUV***

## I. INTRODUCTION

Current passive acoustic systems for marine mammal monitoring suffer from significant drawbacks for enabling real-time mitigation of anthropogenic activities: data from archival underwater recorders gets processed weeks or months after the activities being monitored; towed hydrophone array data is compromised by the noise of the tow ship; and existing near-real-time systems operate with delays on the order of 30 minutes [1]. To address these drawbacks, the Cornell Lab of Ornithology's Bioacoustics Research Program (BRP) and Science Applications International Corporation (SAIC) are collaborating to develop a Mobile Marine Mammal Monitoring (M4) system capable of transmitting Detection, Classification, and Location (DCL) data in real-time to an on-ship or on-shore Data Management and Communications (DMAC) receiver. Overall project objectives are to

1. Integrate a four-channel hydrophone array, data acquisition (DAQ) electronics, and a satellite communications (Satcom) system [7] with a Wave Glider.
2. Acquire marine acoustic data using the M4 system developed in (1).
3. Transmit selected acoustic data and associated metadata in real-time to the DMAC receiver via a high-speed satellite data link [7].
4. Optimize detection, classification, and localization (DCL) operations on-board the Wave Glider and at the DMAC receiver to achieve real-time performance similar to a current near-real-time system [1].

The project has thus far demonstrated feasibility for the first three goals, and work is ongoing for the fourth goal. Mechanical and electrical integration of the hydrophone array, DAQ, and SatCom is completed. Field tests have shown the system's ability to acquire marine acoustic data and successfully transmit data via Satcom. Raven computer software [8] is being modified to include (a) a detection algorithm for North Atlantic Right Whale vocalizations, following the work of Gillespie [9]; (b) the capability to import sounds directly from an IP address as they are written, to accommodate the SatCom transfer of data; and (c) the capability to output detections to a database.

## II. BACKGROUND

The following existing technologies are being modified as needed and integrated into the system: (a) a multi-channel hydrophone array; (b) multi-channel acoustic data acquisition electronics; (c) the Raven sound analysis software; (d) the broadband satellite communication subsystem; and (e) the Wave Glider autonomous vehicle. Additional system control and local communications electronics are also being integrated.

### *A. The multi-channel hydrophone array*

Prior to this project, SAIC developed a 15-channel hydrophone array suitable for towing by an unmanned vehicle

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**Figure 1. The multi-channel hydrophone array to be used with the Wave Glider.**

or for use in a static deployment. The array is 4m in length, with a 20cm inter-hydrophone spacing, and an operational depth of 100m. The hydrophones have a nominal sensitivity of -168±3 dBV/μPa with a 15V supply. The array was intended for low power operation, as the entire array consumes 1.5W, or approximately 100mW per hydrophone. The array is shown in Fig. 1. Because of its availability and suitability for the Wave Glider, this array was chosen for integration into the M4 system.

### *B. Multi-channel acoustic data acquisition electronics*

Also prior to this project, SAIC had developed a four-channel data acquisition (DAQ) electronics package intended for low-power operation. The DAQ contains 24-bit A/D converters, configurable gain and filtering, a USB interface, RS-232 and RS-485 interfaces, and an SD card slot for data storage. However, the DAQ was designed for a maximum sampling frequency (Fs) of 3kHz per channel. To make use of the hydrophone's sensitivity up to 10kHz, the DAQ firmware was modified and its performance tested for Fs > 20kHz.

### *C. Raven*

Raven is a software application for the acquisition, visualization, measurement, and analysis of acoustic signals. Raven was developed by BRP [8] with the support of the National Science Foundation to provide a powerful, user-friendly research and teaching tool tailored to the needs of biologists working with acoustic signals. Raven has existing capabilities in multi-channel data acquisition, detection algorithms, and signal bearing estimation, which are all being modified for use with the M4 system under development. Display capabilities of Raven that may be used in this application include spectrograms on different time scales, results of detector algorithms shown overlayed on the spectrograms, and measurements tabulated alongside the spectrograms.

### *D. The Broadband Satellite Communications System (Satcom)*

One significant challenge in the proposed research is transmitting the acoustic data from the WaveGlider to an on-shore or on-ship DMAC facility. Until recently, only low-speed satellite communications payloads with data rates less than 10 kbps, such as Iridium and GOES, have been available for small maritime platforms such as buoys and unmanned vehicles. These systems generally cannot transmit real-time acoustic data due to their limited bandwidth.

To overcome this problem, the M4 system will integrate SAIC broadband satellite communication (Satcom) technology, developed for high-speed data access to small buoys. SAIC has used this technology successfully on small Navy buoys [10], but it has not been demonstrated on autonomous vehicles. The Satcom uses a novel antenna array design and link protocols to decouple buoy motion from satellite tracking for omni-directional high-speed global communications in dynamic seas. Field tests conducted prior to this project showed the system can maintain data transmission rates exceeding 100 kbps, with burst rates as high as 200 kbps. The antenna radome is composed of a dielectrically-matched, durable thermoformed material for resilience and waterproofing.

### *E. The Wave Glider*

The Wave Glider is a relatively new class of autonomous maritime vehicle that harvests wave and solar energy for all vehicle functions including propulsion and electronic payloads [11]. The Wave Glider was originally developed for humpback whale call monitoring in Hawaii [5], and it consists of three major components as shown in Fig. 2: a surface expression (float), a subsurface wing (glider), and an electromechanical tether connecting the glider wing to the float [4]. The float is a composite, foam filled float body that houses solar panels, rechargeable batteries, platform electronics, antenna, and two payload bays. The pressure vessel contains the DAQ and connects to the hydrophone array, both of which were integrated into the M4 system for this project. The Wave Glider technology enables portability, autonomy, and persistence in the proposed real-time M4 system. It can be deployed from a small ship in an area of operation or it can be swum from a nearby port or harbor, to station-keep for monitoring a selected ocean area or to follow waypoints to perform surveys.

## III. METHODS

To accomplish the four project objectives described above, the following developments are being pursued.

1. Hardware integration of the hydrophone array, DAQ, and Satcom with the Wave Glider
2. Lab and in-water testing of the M4 system
3. Processing the in-water data with the Raven-based remote DMAC interface

### *A. Hardware Integration*

Four of the 15 hydrophones in the array were chosen for use in the M4 system based on similarity in sensitivity over frequency. Pre-amplifiers were designed and integrated with

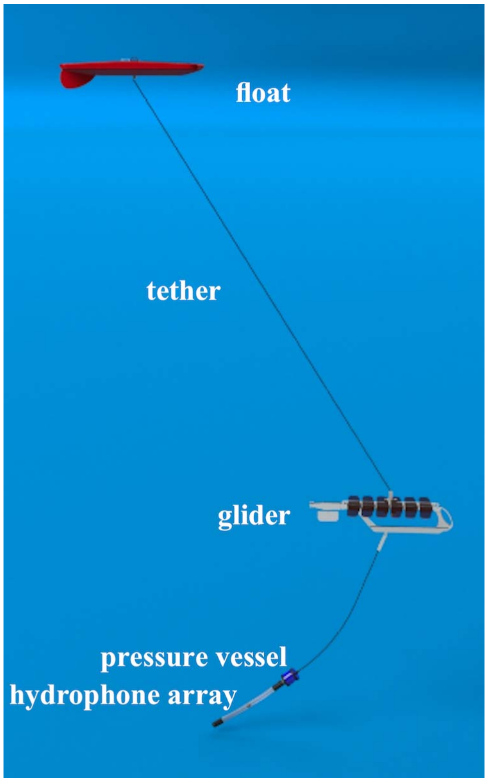


**Figure 2. M4 system components: Wave Glider float, tether, and glider; pressure vessel containing DAQ; and hydrophone array.**

the DAQ in the pressure vessel to power and receive signals from only those four hydrophones, and to allow remotely programmable gain and filter settings. The DAQ electronics and firmware were modified to achieve Fs=26.042kHz. The Satcom integration required mechanical modifications to the antenna design and electronic modifications to the terminal. An additional input/output control electronics board was designed and integrated to handle routing the on-board data transfers and controlling the DAQ and Satcom.

### *B. Lab and In-water Testing*

The M4 system was tested in the lab for system power consumption and data throughput over the Satcom. The Wave Glider float was connected to a load and its battery level was monitored for one week, while it cycled between being charged via its photovoltaic panels during the day and being drained overnight, to predict the expected maximum deployment length.

The M4 system was twice deployed in the Gulf of Mexico for in-water testing – once in June of 2012 and again in June of 2013. In the first deployment, the goal was to demonstrate successful acquisition of four channels of acoustic data on-board the Wave Glider only. Test stimuli, consisting of single-frequency tones, simulated right whale vocalizations and actual right whale vocalizations from BRP's archives, were played into the water near the vessel. The goal of the second deployment was to demonstrate the Satcom's ability to transfer acoustic data to a remote DMAC.

**Figure 3. Wave Glider with integrated Satcom radome.**

### *C. Modifying Raven for processing M4 data*

The BRP data processing and visualization software Raven was modified to incorporate the following functions: direct import of the four-channel multiplexed data recorded by the DAQ, real-time processing of the imported data with a Detection-Classification (DC) algorithm described by Gillespie [9]. With these two modifications, data retrieved from the Wave Glider, either from the DAQ SD card or via Satcom transfer, can be placed into a folder and treated as incoming streaming data to simulate the real-time DMAC process that is being developed.

## IV. RESULTS

### *A. Hardware Integration*

The fully integrated M4 system is shown in Fig. 3 prior to the second deployment. The hydrophone array, DAQ, Satcom, and associated electronics were measured in the lab to consume 6W on average. A 6W load was used for the Wave Glider PV panel and battery system test, to estimate the maximum deployment duration of 60 days from the one-week linear fit (Fig. 4). The Satcom system was tested for transfer speeds with File Transfer Protocol (FTP) and User Datagram Protocol (UDP). Average speeds in the lab tests were 80kbps and 200kbps, respectively. For the goal of transmitting relatively brief (e.g., 2s) clips of data, assuming Fs=26.042kHz at 24 bits, about 6.25s will be required to transfer each clip – almost 300 times faster than a near-real-time system currently in use [1].

### *B. Raven modifications*

With the modifications described above, running the detector process in Raven on the incoming data results in a user display as shown in Fig. 5. Here the recorded signals are synthetic right whale calls, and the DC algorithm events are marked as purple boxes. Note that not all of the calls are marked, because the duration and frequency range of the calls were varied within and outside the range expected by the DC algorithm.

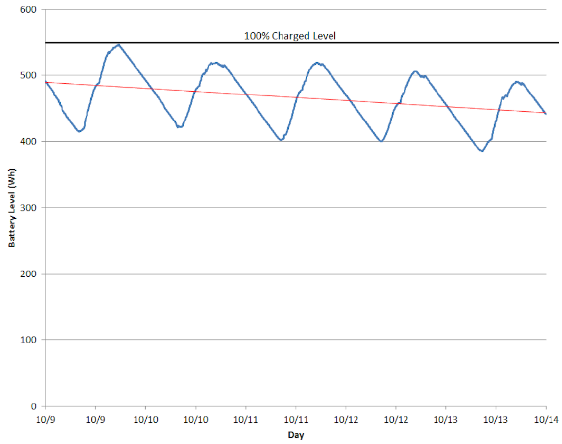


**Figure 4. Wave Glider battery level (blue) and linear fit (red) over a one-week charge-discharge cycle using a 6W constant load to predict a 60-day maximum deployment duration.**

### C. *In-water testing*

During the first deployment in 2012, ambient noise specific to the test location was more intense than all but the loudest test stimuli. While the test did demonstrate the M4 system's ability to capture and store four channels of hydrophone data, unfortunately this first test relied on physical retrieval of the data from the SD card on the DAQ in the pressure vessel, meaning that the excessive noise was not apparent until data review on shore. During the second deployment in 2013, at a different location, the M4 system successfully transferred a 30s data file via Satcom to SAIC in Long Beach, MS. About five minutes was required between the initiation of the Satcom transfer at the Wave Glider to the confirmation of receipt at SAIC, or about a 60kbps transfer rate. However, that estimate is low as the confirmation occurred over a separate satellite voice link. A more accurate transfer rate will be estimated in a future deployment by comparing GPS time-stamped initiation and reception times. An example of some marine mammals (dolphins) recorded serendipitously during the second deployment is shown in Fig. 6.

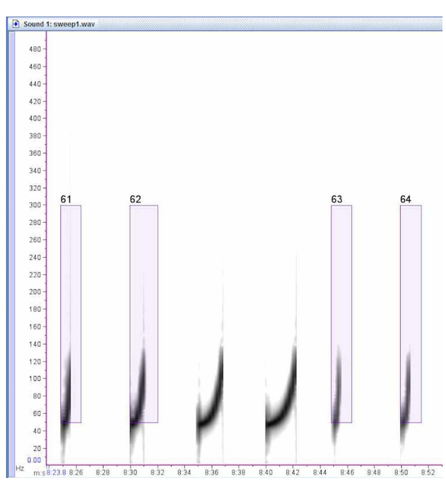


**Figure 5. Raven screenshot showing events (purple boxes) as marked by the DC algorithm. The signals shown are synthetic right whale calls.**

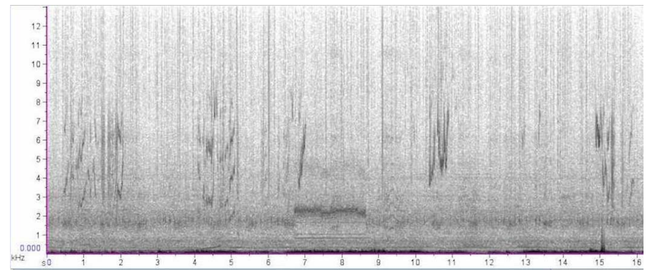


**Figure 6. Raven screenshot showing spectrogram of dolphin vocalizations as recorded by the M4 system during the second deployment.**

## V. SUMMARY & FUTURE WORK

The M4 system development aims to prototype a glider-based, real-time, marine mammal monitoring system that can be remotely deployed and whose data can be remotely reviewed via satellite communication. Such a system should increase the effectiveness of conservation efforts as it will provide for efficient monitoring of areas that may not otherwise be surveyed. In addition, it will provide an attractive alternative to the current towed hydrophone array monitoring method for seismic surveys that are limited by their proximity to the intense noise source of the seismic arrays.

Future work will include implementing the DC algorithm on-board the Wave Glider, developing bearing estimation in the Raven user interface based on the four-channel hydrophone array, and conducting a multi-day deployment in an area known to be home to right whales such that the system's real-time capabilities can be evaluated with actual marine mammal vocalizations.

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