

A Multi-Week Behavioral Sampling Tag for Sound Effects Studies: Design Trade-Offs and Prototype Evaluation

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LONG-TERM GOALS

The project will develop new tag technology needed to study the behavioral effects of sound on wild marine mammals over extended intervals. This will enable fine-scale studies of sound exposure and responses under authentic conditions and will provide data needed to assess the biological significance of responses.

OBJECTIVES

1. Develop a multi-week behavioral sampling tag with archival and telemetry capabilities. This tag will be used as a test-bed to evaluate *in situ* behavioral sampling and data summary algorithms.
2. Develop robust data compression and event counting algorithms to deliver information about the baseline behavior of tagged animals and their exposure and responses to sound via satellite telemetry.
3. Evaluate the new methods in field experiments on marine mammals.

APPROACH

Studies of the impact of human-sourced sound on marine mammals require tags capable of sampling both the behavior of, and the sounds experienced by, animals. Short-term sound recording tags such as the DTAG have enabled controlled exposure experiments, yielding fine-scale data about how animals respond to sounds. The challenge now is to extend the duration and sensitivity of these studies to provide information about longer-term responses under more authentic sound exposure conditions. A target goal is to monitor animals during Navy sonar exercises that may last up to a week. Including baseline periods before, and return to baseline after, the exposure, a tag duration of two or more weeks is required. Given this duration, there is a significant risk that tags will not be recovered and so essential information must be transmitted via radio telemetry. There is a tremendous mis-match between the high data rates that can be collected on a tag and the low data rates that can be sent by telemetry, and so this constraint requires careful selection and compression of data. Power

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consumption is another limiting factor in a multi-week device. Thus, key challenges are to identify meaningful behavioral and environmental metrics that can be (i) acquired with low power by a tag and (ii) represented by very few data bytes for satellite telemetry.

Existing telemetry tags provide reliable long-term information about movements and diving rate but the necessarily low sampling rate of these tags makes them largely unsuitable for studying reactions to sound exposures. The approach taken here is to combine fast-sampling multi-sensor archival tag technology with smart data selection/compression algorithms and store-and-forward telemetry. We envisage a tag that is capable of recording sound and fine-scale movement data continually over a 2 week period, computing at the same time a set of compact summary statistics for later transmission. Upon release from the animal, the tag will float at the surface transmitting the summary data via GSM or satellite radio, powered by small solar panels. The tag will also contain a full archive of the sound and sensor data in case it is possible to retrieve it. There are significant technological challenges to overcome in creating such a device. First, the power consumption of current tags must be reduced substantially. Secondly, robust methods for detecting key behavioral and acoustic exposure events must be developed and implemented in the tag. The compression factors required are enormous (e.g., compression from 30 GB to roughly 30 kB is needed for Argos telemetry) making this a complex task. The third challenge is to learn how to draw statistical inferences from such highly compressed data and therefore how to design experiments or opportunistic studies that maximize statistical power. To meet these challenges, we will:

- 1) Develop a hybrid sound and movement sampling tag with both archival and telemetry capabilities. This device will be programmable and capable of advanced signal processing but will have low power consumption for multi-week deployments. The hybrid tag will be field-tested in settings where there will be, at least initially, a high chance of tag recovery allowing direct comparison of the telemetered and archival data sets.
- 2) In parallel, we will develop detection, compression and summary methods that deliver the critical data needed for assessing behavioral responses within limited telemetry bandwidths. These algorithms will be tested using existing DTAG data and then ported to the hybrid tag for field evaluation. Work will be guided by a workshop bringing together experts in animal behavior, tag design and statistical inference.

WORK COMPLETED

Goals for the first year of the project are:

1. Adapt the existing DTAG design to produce a hybrid archival and telemetry tag. This will serve as a test-bed for the field evaluation of behavioural summary algorithms in the second project year.
2. Begin the development of data compression, event counting and summary algorithms. These will be tested in simulation using existing DTAG data and successful methods will be ported to the new tag for field evaluation.
3. Hold a workshop of experts in on-animal behavioural sensing, data compression and response studies to evaluate the performance trade-offs in medium-term tags.

Funds for this project were delayed for several months and their arrival in late spring coincided with summer fieldwork for most of the PIs leaving less time than anticipated for the project. Despite this, significant progress has been made on the tag and algorithm design tasks. The hybrid tag design is based on the WHOI version 3 DTAG but incorporates several novel circuits to meet the longevity and telemetry objectives. These include: (i) a low-power sound acquisition system, (ii) dual battery switching and solar charging, (iii) extended memory, (iv) a fast acquisition GPS, and (v) an ARGOS interface. Prototypes of these critical circuits have been constructed and are now being tested. We are taking advantage of several field opportunities to test subsets of the new circuits at no cost to the project. A DTAG with extended memory and dual power sources has been constructed for use as a glider-borne autonomous recorder. This device has been bench tested and will be trialed at sea in October 2012. A DTAG with GPS is also being readied for field testing in October. The prototype hybrid tag will be completed during the winter and will be field tested on porpoises in early 2013 in a cooperative project with the Universities of Hannover and Aarhus.

Work on algorithm design for the hybrid tag has advanced on two fronts. We have improved the performance of the lossless sound compression algorithm used in the DTAG and reported the method in a journal article. This paper compares the performance of several other compression algorithms to determine the likely limits of lossless compression as applied to underwater sound. We conclude that the compression factors achieved by these algorithms are nowhere close to those required to telemeter behavioral data from a tag, but these methods may be valuable to transmit critical sound samples such as during a sound exposure. To summarize behavioral data, event counting methods will be required and we have begun exploring how to count foraging and locomotory events in existing DTAG data from beaked whales. This work will be discussed in the following section.

A consequence of the late start is that the workshop, initially planned for the July-August time frame, was not put in place and is now planned for early 2013. The primary objective of the workshop is to define a set of data summary methods that enable robust behavioral inferences within the limited bandwidth of satellite telemetry. Thus the workshop will be mostly focused on software and experiment design. Despite the delay, the workshop will still occur early enough in our software development cycle to be able to incorporate the findings into tags for the 2013 field season. A preliminary list of workshop attendees has been discussed with the program manager and is as follows:

Bill Burgess, Greenridge

Mike Fedak, SMRU/U. St. Andrews

Doug Gillespie, SMRU/U. St. Andrews

Mark Johnson, SMRU/U. St. Andrews

Holger Klink, U. Oregon

Phil Lovell, SMRU/U. St. Andrews

David Mann, U. South Florida

Bernie McConnell, SMRU/U. St. Andrews

Len Thomas, CREEM/U. St. Andrews

Peter Tyack, SMRU/U. St. Andrews

Michael Weise, ONR

Given that 7 of the 11 participants are located in St. Andrews, we plan to hold the workshop there and a date in January-February 2013 will be decided shortly. The workshop will comprise 2 days of round-table discussions. A discussion document and test data set will be made available to participants well before the workshop. The PIs will evaluate a number of existing event counting and behavioural state estimation algorithms on this data set and report the findings at the workshop.

Another change in the project plan has been discussed with the program manager. It was originally planned to recruit a PhD student to perform algorithm development work for the project. However, on consideration, the PIs concluded that the mix of capabilities called for would exceed those of a graduate student whether from a biology or a maths/physics/engineering background. We propose instead to recruit a part-time research assistant to assist the PIs in producing and testing the hybrid tags. This will free PI time for the more challenging task of developing event detection and data summary algorithms for the tag. The research assistant will be funded by the budgeted student support and so will not change the cost of the project.

RESULTS

Work in the first 6 months of the project has focused on resolving some of the challenging hardware and software issues in the hybrid tag. Overall size of the tag is a critical determinant of its practicality for fielding on beaked whales. Tag size is in turn dependent on power consumption as the battery, and the associated floatation, represents a major part of the tag volume. Bench tests of the new tag components indicate that the hybrid tag will consume about 30 mW, meeting the proposed design goal for a 2 week deployment. This power can be sourced from an 'AA' size Lithium primary (non-rechargeable) cell while the tag is attached to an animal and then from a rechargeable Lithium-ion cell with solar charging when the tag releases and is transmitting data at the surface. As a result of the small batteries, the tag will have a volume only 20% greater than the DTAG-3 making it small enough for reliable deployment on delphinids and beaked whales.

The tag software will include both data compression and data summary algorithms. As a first step in exploring data compression methods, we have completed a journal paper showing that underwater sound data can be compressed by a factor of up to 7 using a simple lossless compression algorithm. This algorithm, an improvement of the method used for some years in DTAGs, will be distributed as open-source software enabling longer and higher bandwidth recordings in any microprocessor-equipped tag or autonomous recorder. The paper demonstrates that the simple algorithm achieves almost 90% of the compression achieved by more complex adaptive algorithms but that compression factors much beyond 7 are unlikely with any form of lossless compression. Although compression factors of 30 or more may be possible with lossy compression, these algorithms introduce artifacts that may impact inferences drawn from the data. These results confirm that only brief critical samples of sound can be delivered via telemetry making it imperative to identify reliable ways to summarize sound and movement data.

In evaluating data summary methods, we have focused initially on beaked whale foraging dives both on account of the importance of these in behavioral response studies and because these dives are relatively stereotyped making them a good candidate for on-board processing. We have shown previously that high frequency acceleration dynamics are associated with prey capture attempts (Johnson et al. 2004). Applying this technique to DTAG data from Blainville's beaked whales, tagged under a NOPP project, we have found that acceleration transients coincide with over 90% of prey capture buzzes. We are currently exploring whether prey handling following successful captures

increases the duration and intensity of these transients potentially providing a way to quantify foraging success. To ground truth this, a PhD student supervised by Prof. Madsen at Aarhus University attached DTAGs to porpoises in a Danish aquarium (The Fjord and Baelte Center, Kerteminde). The tagged porpoises were videoed with underwater cameras while approaching and capturing both live and dead fish to help interpret the acceleration dynamics recorded by the tags. This work is currently being prepared for publication.

Although acceleration transients can be easily detected and counted during the foraging phase of dives, similar signatures are also found during ascents from deep dives. Beaked whales produce peculiar high amplitude fluke strokes in ascents interspersed with glides and regular fluking. These strokes may form part of an energy-saving technique to extend the duration of foraging dives and, if so, may provide an indication of the physiological stress of the animal. A PhD student supervised by Drs. Johnson and Miller at the University of St. Andrews is currently developing stroke and glide detectors with the objective of determining when and how often beaked whales use high-amplitude strokes. A paper is currently being prepared on this work. To distinguish acceleration transients associated with prey capture from those caused by stroking, it is critical to determine the diving state of the animal, i.e., whether it is descending, foraging or ascending. All beaked whales tagged to date have performed silent ascents making it possible to use the production of echolocation clicks as a cue to distinguish dive states. Thus, despite the stereotypy of these dives, multiple sensor data sources are required to reliably sequence diving behaviour and quantify prey capture attempts. Echolocation clicks from a tagged beaked whale are relatively straightforward to detect in a tag and will be the focus of our initial on-board data summary algorithms.

IMPACT/APPLICATIONS

National Security

Concern about potential impacts on acoustically-sensitive cetaceans has constrained some Navy activities. The project will develop critical tag technology needed to study the effects of sound on cetaceans over extended intervals and under authentic conditions. This information will strengthen models of population-level consequences of sound and will aid in Navy planning

Economic Development

Economic development brings increasing noise to the ocean from ship traffic, construction, and mineral exploration. An improved understanding of how noise impacts marine mammals will help to make economic growth sustainable.

Quality of Life

The project will contribute to our understanding of deep diving cetaceans and their sensitivity to human interactions. The techniques developed here will improve the efficacy of acoustic surveys facilitating improved regional management.

Science Education and Communication

The project is focused on disseminating information and developing capacity in the areas of behavioral monitoring of cetaceans and their responses to noise. Results from the project will be presented at conferences and in the scientific literature. Software and hardware products of the project will be freely available to the research community.

TRANSITIONS

A journal paper describing a sound compression algorithm has been accepted for publication. This paper will be supported by a web-site containing sound samples and open-source software to foster community-wide evaluation of sound compression and archiving methods. The compression algorithm has already been implemented in the PAMGUARD software.

RELATED PROJECTS

Funds have been obtained from the German federal office of nature conservation (BFN) via a sub-contract with Hannover University to develop and deploy a multi-day Argos-equipped DTAG for porpoises. This tag is needed to establish individual vocalization rates and movement patterns of porpoises which will improve the design of passive acoustic monitoring networks in Europe. The project has strong synergy with the ONR project: the BFN tag requires a subset of the capabilities of the tag required for the ONR project thus creating intermediate milestones for development and evaluation. The BFN tag will be applied to by-caught animals that are temporarily restrained providing an excellent opportunity to assess the performance of multi-day suction cup attachments on animals with known skin condition. Although ARGOS capability is required in the BFN tag simply to locate tags when they have released, we will use deployments of the tag as a low-risk opportunity to trial data summary algorithms developed under the ONR project. As the BFN tags will be retrieved with high probability, the performance of the summary and transmission algorithms can be directly compared against the archived data.

PUBLICATIONS

Johnson M, Partan J, Hurst T, "Low complexity lossless compression of underwater sound recordings".
J Ac Soc Am. [in press, refereed]