Report on tomographic and geophysical inversions from opportunistic sound sources

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LONG-TERM GOALS

The ocean is full of biological and other naturally-generated sound sources that could be used to develop and demonstrate advanced acoustic localization and inversion concepts. Unfortunately, these sources are often located in hostile and isolated environments where deployment of sophisticated array systems is difficult, expensive, and inflexible. A prototype modular array has been built, where each element records data directly to a local flash memory, permitting the elements to be connected by rope instead of cable. This permits the elements to be arranged in various configurations, including towed horizontal arrays, bottom-mounted horizontal arrays, and vertical arrays, both short and wide-aperture. All array deployments are expected to be light enough to be deployed from a small motorboat, and flexible enough to be moved and redeployed multiple times a day. The result would be a compact, rugged, and unobtrusive system that can be used to conduct multi-element array localization and inversion studies on biological and anthropogenic sources of opportunity with minimal field resources and lead time.

OBJECTIVES

The overall project goal is to modify flash-memory recorders, originally developed for marine mammal acoustic tags[1-4], into modular, portable, and rugged array systems that can be deployed in multiple configurations, from platforms as small as a kayak. The elements would be time-synchronized either through active acoustic methods, or passively using ambient ocean noise. This array system would then be used to illustrate increasingly advanced acoustic signal processing techniques on various sources of opportunity, with an emphasis on marine mammals:

(1) Azimuthal tracking with a horizontal array configuration, data from Scripps Pier.
(2) Plane-wave beamforming on a vertical array configuration, scheduled to be tested on blue whales in Monterey Bay, 2003.
(3) Matched-field processing and tracking of low-frequency signals with a vertical array, to be tested on humpback whales in Australia, Nov. 2003.
(4) Geoacoustic inversion of sound speed and bottom profiles, on humpback whales in 2003 and blue whales in 2004.

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APPROACH

Supplemental support from the ONR Marine Mammals program (N00014-03-1-0460) was used to help fund the construction of six autonomous flash memory recorders, slightly modified versions of acoustic "bioprobes[1,2]" built by Bill Burgess of Greeneridge Sciences, Inc. The original probe design had 255 MB of memory and a pressure and temperature sensor encased in epoxy, with a small lithium battery that limited its effective recording life. For this project the electronics were instead inserted into acrylic pressure cases to permit regular AA batteries to be used (thus providing more energy), to allow different hydrophones to be substituted, and to permit a memory upgrade from 1 to 2 Gb in FY 2004. In addition an accelerometer to measure instrument tilt was incorporated. In both designs all data is transferred from flash memory via infrared transfer using a serial port protocol through the transparent housing (Figure 1).

These autonomous recorders record acoustic data independently, eliminating the need for wires and strong mechanical cables, but sacrificing the ability to monitor the signals in real-time. The data across multiple instruments also needs to be time-synchronized by using a combination of active acoustic pulses[5,6], ambient ocean noise[7], orr even marine mammal vocalizations themselves, using so-called "focalization[8,9]" techniques. The auxiliary pressure, temperature, and tilt data would be used to determine the relative position of the elements to aid in the time synchronization. The time-synched data could then be used to test a variety of beamforming and inversion techniques for both vertical and horizontal array deployments. After engineering tests conducted off the Scripps Pier in August 2003, a first test of the system will be on foraging blue whales in Monterey Bay in September 2003, as part of a collaborative research effort with John Calambokidis of Cascadia Research, Inc. This work will attempt to demonstrate vertical plane-wave beamforming on blue whale vocalizations for possible localization and bottom inversion.

In November a vertical array deployment will be tested on migrating humpback whales in Australia as an add-on to work performed by the Humpback Acoustic Research Consortium (HARC), lead by Mike Noad of University of Queensland, Doug Cato of Defense Science and Technology Organization (DSTO), and Dale Stokes and Grant Deane of the Marine Physical Laboratory. Matched-field processing and geoacoustic inversion techniques will be attempted on baleen whale vocalizations, using ground-truth information from a real-time localization system already installed on-site by Mike Noad[10-12].

WORK COMPLETED

Four recorders in pressure cases were ordered in December 2002 using the ONR Entry-Level Acoustic Faculty Award (N00014-03-1-0215). In February 2003 a supplemental grant from ONR Marine Mammals (N00014-03-1-0460) become available to purchase two additional recorders, this time based in epoxy to permit potential deployment to depths greater than 300 m. This supplemental support permitted construction of a six-element modular array while ensuring enough funding for fieldwork and salary support.

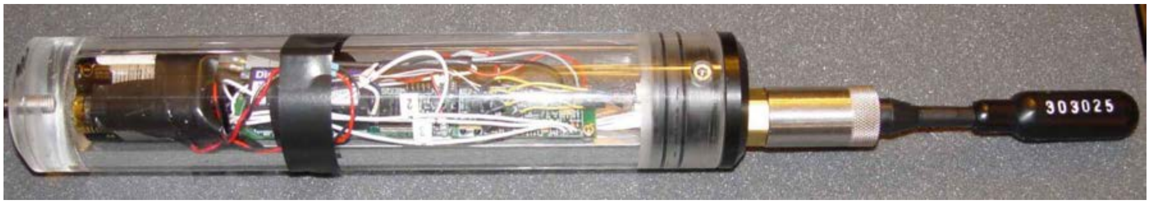


Figure 1. One of six autonomous recorders based on bioacoustic probe design of Bill Burgess of Greeneridge Sciences, Inc. Note the presence of 4 AA batteries, which provides sufficient power to fill 1 Gb of memory at various sampling rates. The package also includes a inclinometer, pressure and temperature sensors. The HTI hydrophone is detachable to permit a shore-power connection.

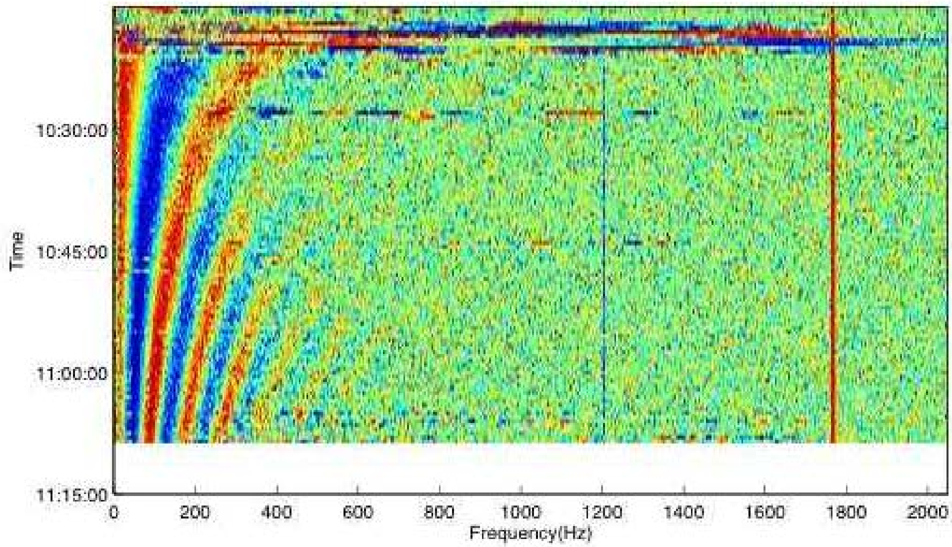
The four pressure-case recorders became available in late May, 2003 (Figure 1). Two pressure-case recorders were deployed in the Gulf of Mexico in June 2003 to check that the recording software and downloading procedure worked, and that the instruments could be deployed as a towed array system. In August 2003 four array deployments were tested off the Scripps Pier in increasingly complex configurations: bottom-mounted arrays with 2 and 14 m separation, a four-element 30 m aperture bottom-mounted vertical array, and a 100 m aperture free-floating vertical array.

The deployment of a 100 m aperture vertical array off the shore of the Channel Islands in the vicinity of a humpback whale from a small sailboat was accomplished on September 13 and 14, 2003. Over the next two months intensive fieldwork in Monterey Bay, CA and Queensland, Australia will begin.

RESULTS

The test deployments off the Scripps Pier not only demonstrated that 100 m long vertical arrays could be deployed from a 13’ Boston Whaler, but it was also found that ambient wind-driven noise could be used to track the relative clock-drift between the recorders, to separations of at least 14 m (Figure 2). The figure shows the equalized complex coherence function[13] between two hydrophone elements, which according to recent work should be related to the Green’s function between both elements[7]. Thus, if the separation between the elements is measured independently (though pressure and inclination sensors), the clock drift between the elements can be measured by noting how the peak of the coherence function drifts over time (vertical axis in Figure 2).

It was found that both horizontal bottom-mounted arrays and bottom-mounted vertical arrays could be time-synched in this manner, but at present free-floating vertical arrays suffer flow noise problems that destroy the spatial coherence function. At this time effort into placing a sea anchor and elastic bungee between the surface floatation and array elements is being explored in an attempt to try to recover spatial coherence. Regardless, it looks increasingly likely that coherent beamforming techniques can be applied to data recorded on separate autonomous recorders, particularly if the acoustic data are sampled at ten times the highest acoustic frequency of interest.



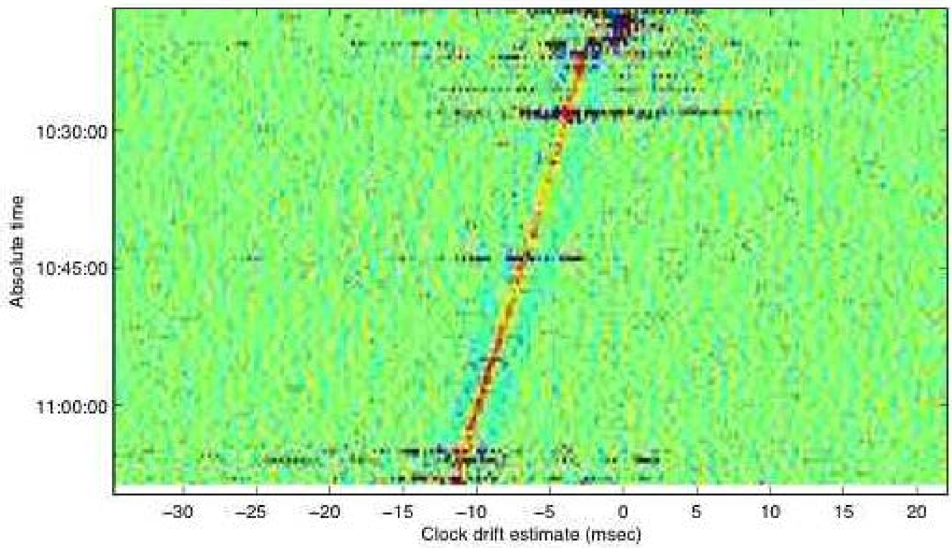


Figure2. Time synchronization between two sensors, spaced 4 m apart, using ambient ocean noise sampled at 4 kHz. Top: complex coherence function vs local time vs. frequency. Desynchronization between the recorders leads to a ripple in the coherence vs. frequency. Bottom: Time-domain coherence function, corrected for element separation. The bright red line shows the relative clock drift as a function of local time.

IMPACT/APPLICATION

The successful integration of several autonomous recorders into a vertical and horizontal array would open up new avenues in ocean acoustic research, particularly for the studies of acoustic signals in regions that have traditionally been difficult to study due to isolation, rough conditions or ecological sensitivities. With respect to marine mammals, the demonstration of this array system would permit unobtrusive passive acoustic studies to take place in remote and environmentally sensitive locations.

These arrays would also allow passive acoustic methods to be integrated more effectively with acoustic tagging and biopsy work, because a portable autonomous array could be deployed from a small vessel, then regularly retrieved and redeployed to follow a group of animals.

RELATED PROJECTS

This equipment is also being used both in ONR Grant# N00014-03-1-0215 and as part of the passive acoustic component of the Sperm Whale Seismic Study (SWSS), funded by the Minerals Management Service. As part of the latter program one of the instruments was towed behind an oceanographic research vessel in an attempt to increase the effective aperture of a towed array already in use by the project . As mentioned previously, collaborative work with the Humpback Acoustic Research Consortium (HARC) in Australia is also being conducted.

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