Instantaneous Passive and Active Detection, Localization, Monitoring and Classification of Marine Mammals over Long Ranges with High-Resolution Towed Array Measurements

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LONG TERM GOALS

The objective of this proposal is to develop approaches to enable instantaneous passive and active acoustic detection, localization, continuous monitoring and classification of marine mammals over *wide areas* spanning hundreds of kilometers or more in range. This will be accomplished using high-resolution receiver array measurements of marine mammal vocalizations (passive) and instantaneous wide-area ocean acoustic waveguide remote sensing [1,2] (OAWRS) and imaging (active) of marine mammals.

OBJECTIVES

Extensive marine mammal vocalization data were acquired with a high-resolution towed horizontal receiver array (ONR-FORA) during the Gulf of Maine 2006 experiment (GOME06) [1,2]. This stage of the project aims to (1) classify the humpback whale vocalizations into song and non-song calls; (2) characterize the types of non-song humpback whale vocalizations that were observed during their Fall feeding season; (3) passively localize the whales from their received vocalizations on the high-resolution towed horizontal receiver array; and (4) determine the spatial distribution of the vocalizing whales and their relation to prey distributions.

APPROACH AND WORK PLAN

Over 12,000 instances of marine mammal vocalizations with frequencies ranging from 10 Hz to 4 kHz were received on the high-resolution 160-element towed horizontal receiver array during the course of GOME06 [1,2]. This roughly 2 week long experiment was funded by the NOPP program (ONR-Sloan Foundation). Roughly two-thirds of the vocalizations were from humpback whales in the 50 to 1000 Hz frequency range. Each vocalization signal was processed to determine its time of occurrence, duration, center frequency and bandwidth by spectrogram analysis. Planewave beamforming was applied to enhance the signal-to-noise ratio (SNR) of the marine mammal vocalizations by rejecting out of beam noise and to determine the azimuthal direction of arrival of the vocalizations. A database of marine mammal vocalization signals was created to catalogue this information and to allow easy access and searches for specific calls.

Individual humpback whale vocalizations were categorized into different types according to its time-frequency characteristics [7,9]. The characteristics of each whale vocalization was added to the database for further statistical analysis and data mining. Series of whale vocalizations were classified as either song or non-song calls, based on the criteria that songs are composed of repeating themes, which could be sub-divided into phrases and units. The rate of occurrence of whale song and non-song vocalizations for a full diurnal period and its daytime and nighttime dependencies were determined. Non-song calls were further classified as repetitive when its occurrence rate exceeded a threshold in each 75 s observation time period.

Four distinct methods that can provide instantaneous or near-instantaneous estimates of source range in the far-field of a single high-resolution towed horizontal receiver array were applied to localize the whales [8]. These methods include (1) synthetic aperture tracking (SAT) [8], (2) the array invariant (AI) [4], (3) bearings-only target motion analysis in modified polar coordinates via the extended Kalman filter (MPC-EKF) [5,6], and (4) bearings-migration minimum mean square error (MMSE) [8]; A contour map showing spatial dependence of marine mammal vocalizations was created and charted to geographic space. This contour map of vocalizing whale distribution was then overlain with the humpback whale prey spatial distributions determined from active OAWRS resonant imaging [1,2].

WORK COMPLETED AND RESULTS

1. Characteristics and classification of whale vocalizations

A sequence of received humpback whale vocalizations were first classified as either song or non-song call sequence. A song session typically consisted of at least two themes and often lasted over tens of minutes, with gaps not exceeding ten minutes between any two themes. An example of whale song recorded on the towed horizontal receiver array during GOME06 is shown in Fig. 1.

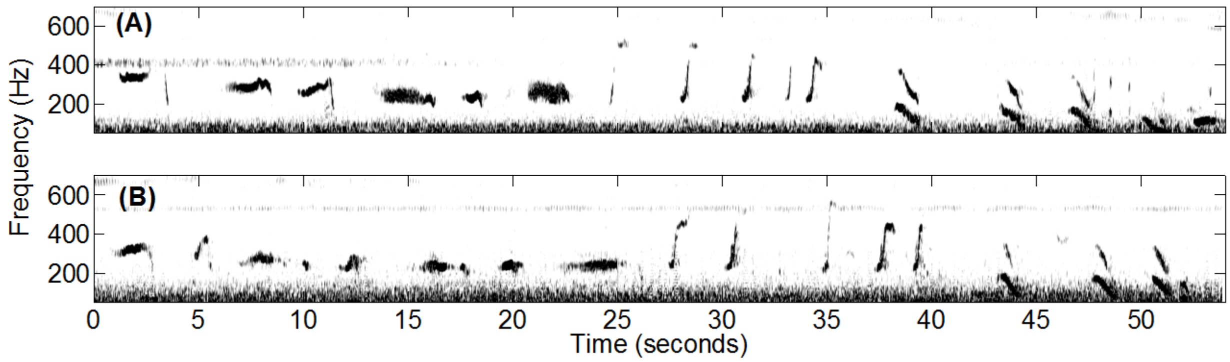

Figure 1. Spectrogram of a typical repeated humpback whale song theme observed during OAWRS 2006 experiment starting at (A) 23:17:44 EDT and (B) 23:49:01 EDT recorded on October 2, 2006 from a singing humpback whale located on the northern flank of Georges Bank.

Each individual whale vocalization signal was further categorized into different types, based on its time-frequency characteristics. Three typical non-song vocalizations were identified: "Meow", "bow shaped" call and "feeding cry" [7]. The time and frequency characteristics of these three types of calls were learned from the large sample set of each type of vocalization. "Meows" and "bow shaped" calls were primarily uttered in series at night, and "feeding cries" only occur at night but far less frequently than "meows" and "bow shaped" calls.

Repetitive non-song calls were observed as series of "meows" or "bow-shaped" calls, which contained at least two similarly structured "meows" or "bow shaped" calls uttered within a short time interval of roughly 31 seconds or 58 seconds, respectively. Random non-song calls were primarily composed of individual "meows", "bow shaped" calls, and "feeding cries" that occurred much less frequently and with less structure.

2. Passive whale localization and tracking from their vocalizations measured using a high-resolution towed horizontal receiver array.

Four distinct passive source localization methods were applied to estimate the range of each whale vocalization received on the high-resolution towed horizontal hydrophone array [8]. The whale localizations were charted onto geographic space and combined to form a contour map showing spatial distribution of the whale vocalizations. The vast majority of vocalizing whales were located on the northern flank of Georges Bank with several hotspots that contain higher densities of whale vocalizations. The diurnal dependencies in the whale vocalization spatial distributions were also determined.

3. Whale behavioral dynamics and relation to prey distribution

The diurnally dependent vocalizing whale distribution map was overlain with distributions of dense and diffuse Atlantic herring populations obtained from concurrent active OAWRS resonant imaging and conventional fish finding sonar surveys[1,2]. Our analysis indicate that the whale vocalization distributions are highly correlated, both temporally and spatially, with their prey distributions during their Fall feeding season in the Gulf of Maine [7].

The future goal of this research is to overlay the passively estimated whale locations onto concurrent active OAWRS imagery [1,2] to determine if it is possible to detect humpback whale individuals from their scattered signals and to determine/infer the whale target strength.

IMPACT AND APPLICATIONS

Combined passive and active acoustic sensing with towed arrays provides an efficient approach for detecting, localizing and classifying marine mammals rapidly over wide areas for many important operations such as geophysical surveys, naval exercises and population assessment surveys that already deploy towed arrays. The research provides training to both female and male graduate and undergraduate students, minorities, and interaction with commercial partners from a wide variety of disciplines including remote sensing and marine mammal biology and so enhances the basic infrastructure of research and education.

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