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 very *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

This stage of the project aims to (1) develop and verify techniques for long range passive localization of marine mammals using their vocalizations measured on a towed horizontal hydrophone array, and (2) to study the vocalization behavior of marine mammals as a function of space and time. The extensive marine mammal vocalization data acquired with a towed horizontal receiving array during the Gulf of Maine 2006 experiment (GOME06) [1,2] are processed and analyzed. The various techniques for passive source localization are first tested for accuracy using one-way transmission data from a known vertical source array deployed during the experiment in the Gulf of Maine. The accuracies associated with the localization techniques are also quantified by modeling.

APPROACH AND WORK PLAN

Over 6000 instances of marine mammal vocalizations with frequencies ranging from 40 Hz to 4 kHz were received on a towed horizontal receiving array during the course of the Gulf of Maine 2006 Experiment. Roughly 60% of the vocalizations were from humpback whales in the 300 to 700 Hz frequency range. Each vocalization signal was processed to determine its time, frequency range by spectrogram analysis, and azimuthal direction of arrival by beamforming the hydrophone array data. A database of marine mammal vocalization signals was created to catalogue this information and to allow easy access and searches for specific calls.

For each received whale vocalization signal, a robust and rapid non-linear matched filter [3] accurately matching the time-frequency spectrogram characteristics of the call was applied to enhance its signal-to-noise (SNR) ratio. The SNR improved by roughly 8 to 10 dB over the standard linear matched filter which provided better whale bearing estimates when the whale calls were beamformed and enhanced whale range localization accuracy.

Four distinct passive source localization methods applicable to intermittent broadband source transmissions received on a towed horizontal receiving array in an ocean waveguide are considered. The four methods were evaluated by applying them to GOME06 transmission data from a known vertical source array that was either drifiting or moored at various ranges from 1 to 23 km and varying azimuths from a towed horizontal receiving array. The transmission signals from the vertical source array were 1 second long broadband chirp pulses of 50 Hz bandwidths with various center frequencies in the 300 Hz to 1200 Hz frequency range with frequency and time characteristics that were within the range of humpback whale vocalizations. Some of the methods were also tested and verified via modeling broadband whale vocalization signals propagated through a random range-dependent ocean waveguide and received on a towed multi-element receiving array.

WORK COMPLETED AND RESULTS

1. Vocalization behavior, diurnal dependence and potential effects of source transmission on whale vocal activity

The marine mammal vocalizations received on the towed hydrophone array were analyzed as a function of time to determine their diurnal dependence and vocalization rates. The humpback whale vocalizations were found to be highly nocturnal with over 85% of the calls received during evening to overnight hours. We also determined the effect of source transmission on whale vocal activity. We found the humpback whale vocalization rate to be independent of source transmissions with an average of 1 call per whale per minute consistent in both presence and absence of source transmissions during their vocally active periods.

2. Developing approaches for passive long range source localization with a single towed hydrophone array

We examined various approaches for instantaneous range estimation and continuous tracking of sound sources over long ranges from passive acoustic measurements made by a single towed horizontal line-array in a random range-dependent ocean waveguide. The key approaches that we considered include (1) the array invariant (AI) method [5], which allows instantaneous localization of acoustic sources located in the far-field of an array in an ocean waveguide with no priori knowledge of the ocean environment and very little computational efforts beyond conventional plane-wave beamforming and matched filtering; (2) the synthetic aperture tracking (SAT) method, an approach that we developed recently which maps the sequential bearing estimates of passive sources and the corresponding GPS-measured receiver array velocity onto a Cartesian grid to estimate the instantaneous source horizontal trajectory; (3) a minimum mean squared error criterion applied to the change of bearings with time to determine the mean position of a transmitting source within a given time period, (4) the conventional bearings-only target motion analysis (TMA), which adaptively predicts and updates the states (horizontal positions and velocities) of the source based on previous state estimates and bearing-only measurements via the extended Kalman filter [6][7].

All passive localization approaches were applied to localize a vertical source array deployed during the Gulf of Maine 2006 Experiment when it was either moored or drifting with the current. The source array transmissions at constant time intervals were received by the horizontal receiver array towed along designated linear tracks each lasting roughly one to two hours with roughly 50 to 100 transmissions. The estimated source locations and inferred horizontal trajectories were compared to the “ground truth” measurements by the shipboard GPS modules and shown in Figs. 1 and 2 for the AI and SAT methods.

High correlations were found between the SAT- and AI-estimated source ranges, and both of the estimates show a consistently good match with the GPS-determined source locations, regardless of the source-receiver geometry. The inferred source horizontal trajectories by the SAT and AI, after employing a linear least squares estimator on the instantaneously estimated source positions, also yield consistently good match with the true source trajectories, except when the error in bearing estimates are large. Overall, we found the accuracy of the estimated mean source locations in each track using the first 3 methods mentioned above were roughly within 100 m of the true source mean location for source-receiver separations of up to 20 km.

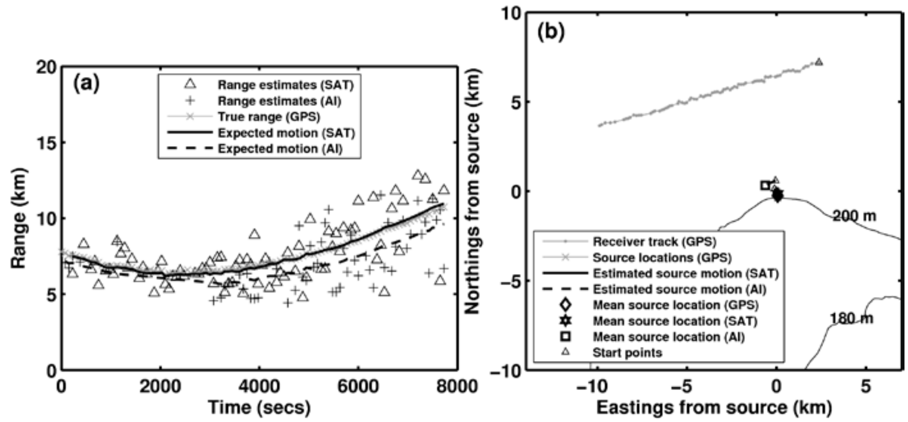

Figure 1. Example of a passive source localization and motion tracking result for the case when the vertical source array was moored and the receiver array was towed from northeast towards southwest as shown in (b). (a) The instantaneous SAT- and AI-estimated source ranges are compared to the GPS-measured "ground truth" values. (b) The inferred source horizontal trajectories and the mean source positions estimated using both SAT and AI are compared with the GPS-derived values.

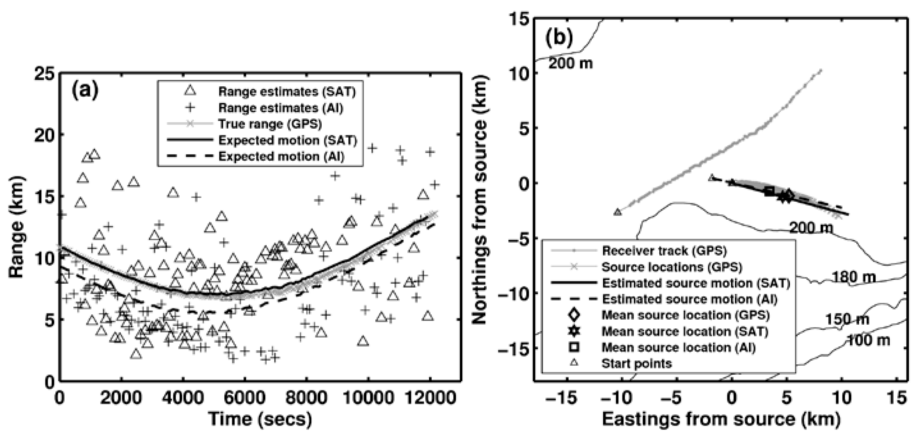

Figure 2. An example of passive source localization and motion tracking result for the case where the vertical source array drifted with the current. a) The instantaneous SAT- and AI-estimated source ranges are compared to the GPS-measured "ground truth" values. (b) The inferred source horizontal trajectories and the mean source positions estimated using both SAT and AI are compared with the GPS-derived values.

For the conventional bearings-only TMA via EKF method, we show that the range estimation results are highly sensitive to system initialization and the premature collapse of the error covariance matrix can lead to a solution that diverges. Because the method was originally formulated for a non-maneuvering target (with constant velocity and heading), this constraint has greatly limited the ability of this method to solve a wide variety of target tracking problems, where the dynamics of the target is random and unpredictable.

3. Preliminary localization results for humpback whales in the Gulf of Maine

Preliminary analysis of humpback whale calls received during GOME06 indicates that the calling whales were mostly located in the Northeastern flank of Georges Bank and the Southeast of Cape Cod. The calling humpback whales could be passively localized out to ranges as large as 70 km from the towed receiving array.

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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