Possibilities for Small-Scale Emission Tomography of Bubble Plumes in Shallow Water

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Abstract: The displacement and spatial distribution of a bubble plume (BP) can be reconstructed by an inversion of the radiated noise field. The quality of reconstruction depends on the oceanic environment, background noise level, characteristics of the measurement instruments and optimization of the reconstruction algorithms.

INTRODUCTION

Tomographic reconstruction of a BP can be reduced to a solution for a Fredholm integral equation of the first kind (in some case, this equation can be reduced to a solution of Fourier or Fresnel transformations when the observation point is far from the noise source and in the Fresnel zone of the receiving array). A coherence function in the observation region can be found after defining the coherence function of the noise source. Then the inverse problem for spatial distribution of the intensity of the noise source can be formulated. According to our inverse problem, we need to find the optimal processing to reach the appropriate space/time resolution and sensitivity required to apply this technique in natural conditions. This problem can be solved by using a priori information about the structure of the oceanic environment and BP noise source. The BP physical model can be regarded as the generator of basis functions for optimal processing.

BP MODEL AND COHERENCE

A direct noise-radiation problem can give a priori information for optimization of the reconstruction procedure. The model used in this paper for the BP is based on the following assumptions: (a) the position and instant of a bubble’s appearance are random and statistically independent, (b) the bubble sizes are the same, (c) the size of the BP is much less than the changes in the ocean’s acoustical field structure and the observation distance, (d) the distribution of bubbles in the cloud is Gaussian and ellipsoidal, and (e) the coherence function of the noise is Gaussian and does not change in time. Using these assumptions, we can get an integral equation for the observed coherence function by replacing the summation of bubbles in the integrand with a density function. Hence, the observed coherence function for the j-projection of the spatial distribution of the bubble cloud will be determined by noise source characteristics, inhomogeneities of the oceanic environment, ambient noise, quality of the receiving system and processing algorithms. Based on the assumption that the bubble cloud is ellipsoidal, it is possible to develop a model of an imaging source as a random distribution of bubbles with spatial density described by an ellipsoidal Gaussian function. Under this model, the observed coherence function will be defined by the displacement of the cloud and its dimensions along three axes. Using them, we define an appropriate aperture functions that provide the optimal processing for reconstructing BP displacement and spatial distribution.

Observed BP noise coherence is limited by the coherence length, which is short for broad band noise. As a result, the optimal time/space durations can be isolated (appropriate trajectories in time/space durations plane). Coherence is maximized along these trajectories. As a result, it is possible to extract the information about the position of the BP by searching for an optimal trajectory. Coherence level along these trajectories is dependent upon the size of the bubble cloud, coherence length and frequency bands used for the analysis. Extracting information about bubble cloud sizes can be done by limiting the frequency band of the analysis and neglecting the influence of limited coherence length associated with this procedure. The sizes of BP can then be estimated by processing the BP noise in an optimal narrow frequency band. Estimated position and size of the BP can be used as the initial values for additional analysis by match field processing (MFP) to reach correct reconstructions when the waveguide modes permit resolution smaller than the BP size.

1423
TOMOGRAPHICAL RECONSTRUCTION PROCEDURE

We developed the following four step procedure for finding the solution of a BP inverse problem, which can be seen as quasi-optimal.

1. Estimation of Displacement. The initial choice of incident angle and distance is made by calculating the trajectory that maximizes the coherence function for a broad frequency band.

2. Estimation of Sizes. The estimate of BP-projection size is done by examining how the coherence function decreases along an optimal trajectory when the frequency band is narrowed. To get this estimate, it is necessary to process all estimations for different regions of frequencies.

3. MFP correction of approximate estimations. The third stage consists of a more accurate choice of position and projection size by MFP on the basis of the allowed physical model. The MFP corrections can be performed over a relatively small region of the parameter space since estimates of these parameter values were found in previous steps.

4. Tomographical Reconstruction of BP. A small number of tomographic projections may be enough for reconstructing the spatial distribution of bubbles because we used a simple parametric model for the noise source. We need at least two projections for reconstructing the ellipsoidal cloud of bubbles. Many projections may be needed for reconstructing more complex BP geometries.

INFLUENCE OF NOISE

Ambient noise limits the accuracy of the tomographic reconstruction. To examine the effects, the scenario described above was recalculated with noise of limited coherence length added to the model. The results indicate that noise leads to distortions of the resultant BP image, which are manifested in additive mistakes in the estimations of positions and BP size. We received 6%-dispersions for estimations of BP displacements for case where SNR = 5 dB.

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