EFFECT OF NOISE FIELD AND ARRAY CONFIGURATION ON MATCHED-FIELD PROCESSING IN UNDERWATER ACOUSTICS

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ABSTRACT

The performance that can be achieved using Matched-Field Processing (MFP) depends on the nature of the ambient noise and the array configuration used to measure the field. In this paper, computer simulations were used to estimate MFP performance for an underwater source in different ambient noise fields and for different array configurations. Best MFP performance was obtained in a thermal ice cracking noise field and poorest performance in a fishing boat noise field. For arrays with fewer than 40 sensors in a surface noise field, best localization was obtained with a vertical array geometry. With more than 40 sensors, billboard arrays (composed of multiple vertical line arrays) outperformed horizontal line arrays which in turn outperformed vertical line arrays.

1. INTRODUCTION

Matched-Field Processing (MFP) may be employed for the passive detection and localization of underwater acoustic sources [1, 2, 3]. In MFP, the measured or predicted acoustic field due to a source is matched with a replica of the field for all possible source positions.

In this paper, we describe the results of computer simulations used to evaluate MFP performance in different ambient noise fields and for different array configurations. Models have been developed to represent three types of ambient noise field: noise generated by surface waves over an infinite half space [4], 'modal noise' generated by a large number of fishing boats in a shallow water waveguide, and Arctic noise generated by thermal ice cracking in a waveguide.

2. THEORY

2.1. Noise Modeling

The acoustic field generated by surface waves was modeled using the classical surface noise model developed by Cron and Sherman [4]. This model was used as a reference for comparison with the other two noise models.

Ambient noise, as might be generated by a large number of fishing boats, was modeled by including 100 widely distributed sources at a depth of 1 m in all simulations. The Arctic thermal ice cracking noise model was similar to the fishing boat noise model, except that the noise sources were impulsive.

2.2. Signal Processing

Matched-Field Processing (MFP) consists of matching the measured noisy field and a model or replica of the field at a single frequency. This is achieved by forming the covariance matrix of the data after Fourier transformation. The eigenvalues and eigenvectors of the covariance matrix are used for the matching or beamforming. A Minimum Variance (MV) beamformer, which is characterized by low sidelobes and high resolution, was employed.

3. GEOACOUSTIC MODEL

A range-independent geoacoustic model was used in this study to represent a shallow water Arctic environment with a high speed (2000 m/sec) bottom and a water depth of 500 m. The water was covered by a 6-m ice layer and had an upward refracting sound speed profile.

A normal mode model was used to represent the acoustic propagation for all cases simulated except the surface noise. Normal modes are a good approximation for signals whose ranges are large compared with the depth of the waveguide. The waveguide supported 12 modes at a source frequency of 24 Hz.

4. SIMULATION CONDITIONS

MFP was performed on simulated data for a source in the shallow water waveguide described in Section 3. For N sensors the simulations employed 3N averages to form the covariance matrix at a signal-to-noise ratio (SNR) of -10 dB. A 24-Hz target at 151 m depth and 25 km range was used for simulation. Ambient noise due to surface waves, fishing boats or thermal ice cracking was also included. Spatially white noise (at 20 dB below the signal level) was added to the simulations as a realistic component usually present which also stabilizes the covariance matrix for processing.

5. SIMULATION RESULTS

The ambiguity surfaces for a 16-element equispaced vertical line array (VLA) in three different noise fields are shown in Figure 1. The VLA extended from a depth of 50 m to the bottom of the waveguide. The target at a depth of 151 m and a range of 25 km can be readily recognized in the plots for the surface and thermal ice cracking ambient noise fields. For the fishing boat ambiguity surface, the target peak is masked by sidelobes or matches with the localized ambient noise sources i.e. fishing boats. Array gain for the array in fishing boat noise was 10 dB below that for

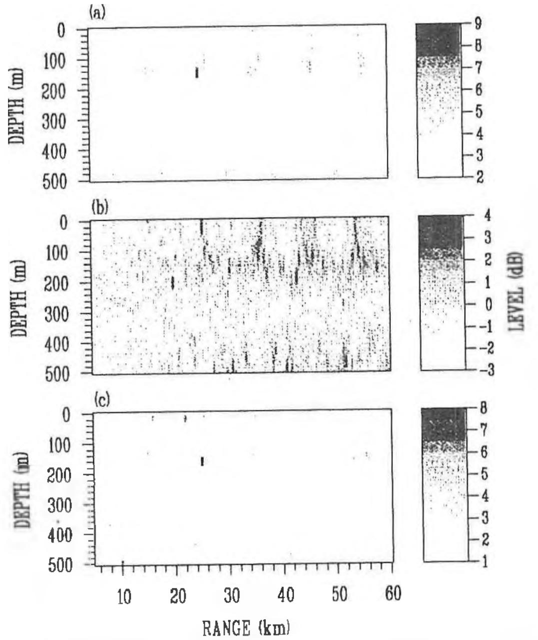

Figure 1. MV ambiguity surfaces for a 475-m-long 16-sensor equispaced VLA in: (a) surface noise, (b) fishing boat noise, and (c) thermal ice cracking noise.

the other two noise fields. Better MFP performance was obtained for thermal ice cracking noise than for fishing boat noise because the former is comprised of impulsive noises which last only for a single snap-shot in time. The impulsive nature and the infrequency of the impulses reduces the contributions to the cross-terms of the covariance matrix that are present in the other two models.

The ambiguity surfaces for a 16-km-long bottom-mounted horizontal line array (HLA) with 16 sensors, with the target at 45° to broadside, and for the same conditions as for Figure 1 is shown in Figure 2. Best performance for the HLA is achieved in thermal ice cracking noise. Because the HLA is able to discriminate noise in bearing, which is not discernable from a range-depth ambiguity plot, higher gains were obtained in the horizontally anisotropic fishing boat noise and thermal ice cracking noise fields than with the VLA.

MFP performance of vertical, horizontal and billboard arrays in surface noise was evaluated as a function of the number of sensors. The billboard arrays (BBA) were constructed from multiple 16-sensor VLAs and spanned a horizontal distance of 4 km. For high SNRs or large time-bandwidth products vertical array performance (array gain and peak-to-sidelobe ratio) reached a maximum at 16 sensors and remained constant beyond 16 sensors, indicating that the modes are properly sampled with a 16-sensor VLA. The performance of horizontal arrays continued to increase as more sensors were added: array gain increased by about 3 dB for each doubling of the number of sensors. For arrays of fewer than about 40 sensors, better localization was obtained with a vertical array geometry than with either a horizontal geometry or billboard geometry. BBAs with more than 40 sensors outperformed HLAs which in turn outperformed VLAs.

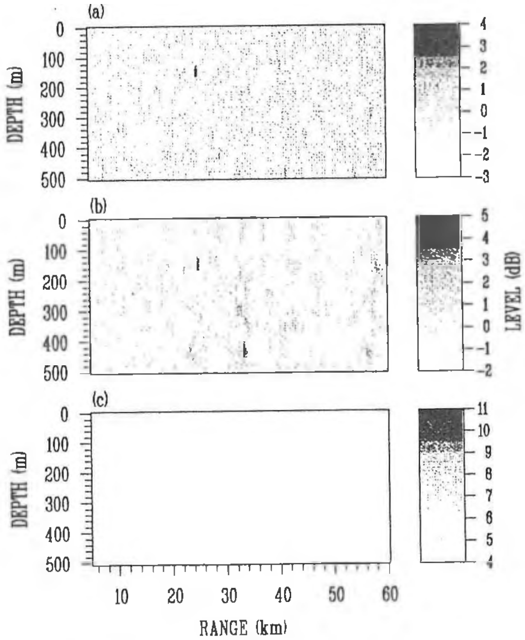

Figure 2. MV ambiguity surfaces for a 16-km-long 16-sensor equispaced HLA in: (a) surface noise, (b) fishing boat noise, and (c) thermal ice cracking noise.

Simulations showed a degradation in vertical array performance with a decrease in array length. Similarly, performance of horizontal arrays and billboard arrays deteriorated with a decrease in horizontal array span.

6. CONCLUSIONS

Simulations showed that the best MFP performance was obtained in a thermal ice cracking noise field and poorest performance in a fishing boat noise field. Performance was evaluated for billboard, horizontal line arrays and vertical line arrays for MV processing in surface noise. With fewer than 40 sensors, best localization was obtained with a vertical array geometry. With more than 40 sensors, billboard arrays outperformed horizontal line arrays which in turn outperformed vertical line arrays.

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