Marine Physical Laboratory

Wideband Beamforming for a Sparse Nonuniform Spaced Sensor Array

Jeffrey Krolik

Final Report to the
Office of Naval Research
for Contract N00014-89-D-0142 (DO#21)
for the Period 06-01-91 - 03-31-92

MPL-U-20/93
April 1993

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University of California, San Diego
Scripps Institution of Oceanography

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. Agency Use Only (Leave Blank).

2. Report Date.
April 1993

3. Report Type and Dates Covered.
Final Report

4. Title and Subtitle.

Wideband Beamforming for a Sparse Nonuniform Spaced Sensor Array

5. Funding Numbers.

N00014-89-D-0142 (DO#21)

Project No.
Task No.

6. Author(s).

Jeffrey Krolik

7. Performing Monitoring Agency Names(s) and Address(es).

University of California, San Diego
Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, California 92152

8. Performing Organization Report Number.

MPL-U-20/93

9. Sponsoring/Monitoring Agency Name(s) and Address(es).

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA 22217-5000

10. Sponsoring/Monitoring Agency Report Number.

11. Supplementary Notes.

12a. Distribution/Availability Statement.

Approved for public release; distribution is unlimited.

12b. Distribution Code.

13. Abstract (Maximum 200 words).

This project concerns the continued development and evaluation of a computationally-efficient wideband adaptive beamformer for a large non-uniformly-spaced sensor array which effectively extends its operation to wavelengths which are considerably smaller than the average inter-element spacing

14. Subject Terms.

broadband beamforming, nonuniformly-spaced sensor array, array processing

15. Number of Pages.
2

16. Price Code.

17. Security Classification of Report.	18. Security Classification of This Page.	19. Security Classification of Abstract..	20. Limitation of Abstract.
Unclassified	Unclassified	Unclassified	None

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Jeffrey Krolik (Principal Investigator)

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Objective

This project concerns the continued development and evaluation of a computationally-efficient wideband adaptive beamformer for a large non-uniformly-spaced sensor array which effectively extends its operation to wavelengths which are considerably smaller than the average inter-element spacing.

Task Report

A requirement exists to extend the useful bandwidth of existing large non-uniformly spaced bottom-mounted arrays to include frequencies where the acoustic wavelength is much smaller than the average inter-element spacing. The performance of a conventional fixed-aperture (FA) delay-and-sum beamformer is seriously degraded at higher frequencies due to: 1) large gaps in the azimuthal coverage provided by a fixed set of beams as a result of the decreasing mainlobe width of each beam with increasing frequency, 2) a loss of multipath signal energy captured within a beam which results when the spread of multipath grazing angles exceeds the mainlobe width, and 3) interferences which leak through beamformer grating plateaux causing both a reduction in array gain and source location ambiguities. Thusfar in this project, an adaptive constant-mainlobe (CM) beamformer has been developed as an alternative means of extending the useful bandwidth of the array. The adaptive CM beamformer maintains a frequency-independent mainlobe response for each beam so as to ensure complete azimuthal coverage by a fixed set of beams over the entire frequency range of interest. Appropriate selection of the frequency-independent mainlobe response not only avoids gaps in azimuthal coverage but also ensures that all multipath arrivals from a common source are captured within a single beam across the full receiver band. Although an approximately frequency-independent mainlobe response could be achieved by simple aperture shading, i.e. using shorter subarrays at higher frequencies, the current design eschews this strategy since it does not facilitate suppression of grating plateaux interferences at higher frequencies where the aperture-shaded subarray is nearly uniformly spaced. Instead, the proposed method achieves a constant mainlobe response by frequency-dependent linear constraints on the adaptive minimum variance solution to the beamformer array response. In the *absence* of interfering sources, the constraint-maintained adaptive CM beamformer response is close to that of an aperture-shaded array. However, since the constraint-maintained adaptive CM solution retains the ability to use the entire non-uniformly spaced array, in the presence of grating plateaux interferences it potentially offers much better array gain and reduced source location ambiguities. In the first phase of this project, the array gain performance of the constraint-maintained adaptive CM beamformer has been evaluated in isotropic ambient noise. Theoretical comparison of the CM versus FA beamformers indicates that the CM beamformer provides a trade-off between main response axis (MRA) and off-MRA array gain. Results up to 400 Hz indicate that the CM beamformer gives as much as a 20 dB improvement over the worst-case response of the FA beamformer at the cost of less than a 5 dB loss relative to the best-case on-MRA FA beamformer gain. Real data provided by NOSC has been used to verify the theoretical array gain comparison up to approximately 180 Hz.

In addition to achieving improved wideband performance, an important objective of this project has been the design of a computationally-efficient implementation of the constraint-maintained adaptive CM beamformer. At the higher sampling rates imposed by larger receiver bandwidths, a conventional frequency-domain beamformer implementation is precluded due to the very long FFT lengths and/or large percent overlap required to handle endfire signal propagation delays. For improved efficiency, an implementation which performs coarse nearest-sample pre-steering of the sensor outputs has been developed. By dividing the full bearing space into sectors and then coarse pre-steering for each sector, the maximum signal propagation delay is reduced to that of an arrival coming from the sector edge. This reduction in the maximum signal propagation delay means that implementation of the beamformer can be achieved with shorter FFT's and/or smaller percent overlap, thus reducing both the computational and memory requirements of the design. Thusfar, implementation of the coarse pre-steered approach has been limited to a non-adaptive CM beamformer which uses the "quiescent" weights of the adaptive CM beamformer in spatially uncorrelated noise. In the continuation of this project, the development of a complete adaptive implementation is proposed.

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