Array Shape Estimation from Sources of Opportunity

W.S. Hodgkiss, P. Gerstoft, and J.J. Murray

Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, CA 92093-0701

***Abstract* - The radiated signatures of ships transiting through an area can be used as natural sources of opportunity for the estimation of array element locations (AEL) and waveguide environmental parameters (e.g. water column sound speed structure, bathymetry, and seafloor geoacoustic characteristis). Using a full-wave model of shallow water acoustic propagation, a matched field processing approach for AEL is demonstrated with horizontal line array data from SWellEx-96 and extended using a simple parametric representation of the array shape along with a genetic algorithm global search strategy.**

I. INTRODUCTION

The coherent processing of data from an array of sensors (beamforming) requires an accurate estimate of the sensor positions. As rule of thumb, the sensor positions must be known to better than $\lambda/10$ at the frequency of interest in order to achieve less than 1 dB loss in (non-adaptive) array processing gain due to errors in array element positions. The need for precise array element localization (AEL) is more important when adaptive array processing is used.

Typically, AEL for a bottomed array is performed by carrying out a well-navigated survey by transmitting broadband pulses at various locations around the array. The pulses either can be generated by a towed source or by explosive/implosive shots (e.g. lightbulbs) [1]. Similarly, a towed CW source also can be used to localize the elements of an array. The arrival structure of these purposefully-generated signals contains the information needed to determine array shape.

Ship signatures contain both significant tonal components as well as substantial broadband energy. Thus, the radiated signatures of ships transiting through an area can be used as natural sources of opportunity for the estimation of array shape.

Our approach to AEL is based on a full-wave model of acoustic propagation in the shallow water waveguide [2]. The individual array element positions are considered uncertain and they are estimated through a searching procedure that maximizes the matched field processor (MFP) output [3]. The processing approach then is modified to use a simple parametric representation of the array shape along with a genetic algorithm global search strategy [4]. The benefit of the latter is that it easily can accommodate the estimation of additional uncertain geometrical parameters (e.g. source

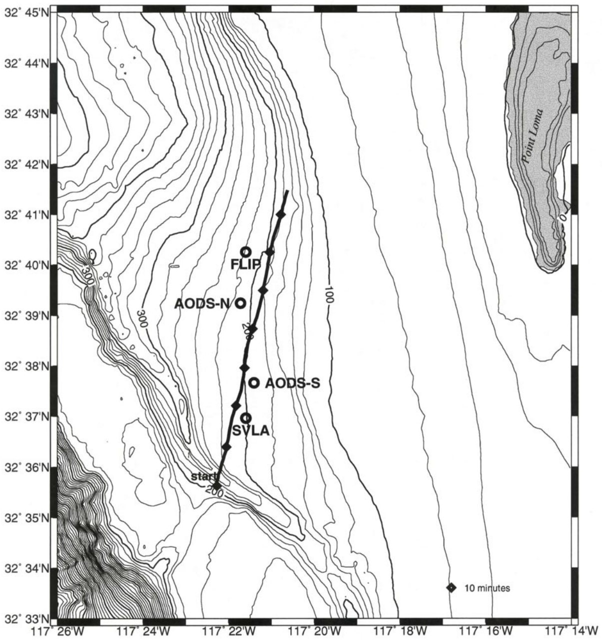

Fig. 1. SWellEx-96 region (SW of Point Loma off San Diego, CA). The AODS array was deployed in approximately 200 m water and consisted of two horizontal segments (AODS-N and AODS-S).

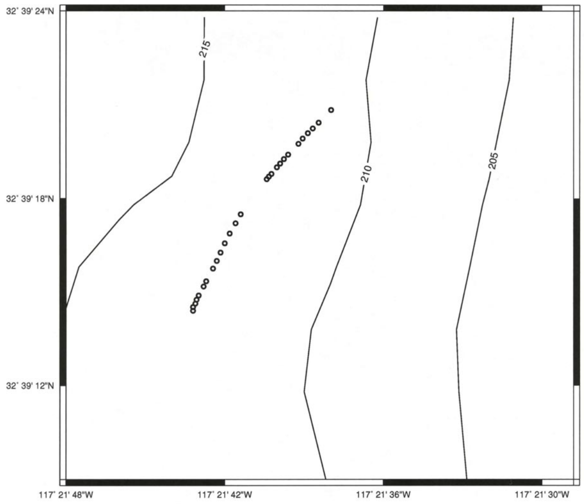

Figure 2. Given array element positions for AODS-N. Note that the array has a small curvature or bow in the NW direction.

range and depth) and environmental parameters (e.g. water column and seafloor sediment sound speed).

II. SWELLEX-96 EXPERIMENT

The horizontal line array data analyzed was from the SWellEx-96 Event S5 source tow track [5]. This provided an opportunity to work with both tonal data from the towed source as well as the broadband radiated signature from the source tow ship. Figure 1 shows the SWellEx-96 region (SW of Point Loma off San Diego, CA). The AODS (All Optical Deployable System) array was deployed in approximately 200 m water and consisted of two horizontal segments (AODS-N and AODS-S). The given array element positions for AODS-N are shown in Figure 2. Note that the array has a small curvature or bow in the NW direction.

Both towed source (60 m deep) and ship signature data were processed. In the case of the towed source, a set of 13 tonals broadcast over the band 50-400 Hz were used. In the case of the ship signature data, 9 frequency components over the band 119-391 Hz were used. For the results presented here, the ship signature data was from the source tow ship. The ship track (SW-to-NE) is indicated in Figure 1. The data processed initially was selected from the near-broadside and near-endfire (north) geometries.

III. MATCHED FIELD PROCESSING APPROACH

The AEL approach investigated is based on maximizing the conventional matched field processor (also called the Bartlett processor) output. Beamforming is most sensitive to array element positioning in the direction of the source (range dimension) and least sensitive orthogonal to the direction of the source (cross-range dimension). Thus, it is highly desirable to observe ship tracks well separated in azimuth with respect to the array.

It is important to include whatever a priori knowledge is available. For example, the array interelement spacing usually is known and provides a useful constraint algorithmically. The ship tracks themselves may be known or roughly known based on radar tracking . Alternatively, ship tracks might be constrained to reasonably well defined shipping lanes or traffic patterns. Lastly, advantage can be taken of knowledge of regional bathymetry, geoacoustic, and water column characteristics.

By using a simple initial approximation to the actual array shape and the known interelement separations, a matched field processing inversion technique was used to determine the individual AODS-N array element displacements in the radial direction from the source of acoustic energy [6]. The radial displacements from the near-broadside and near-endfire orientations of the acoustic source then were used to estimate array element locations north and east relative to Element #1 of AODS-N (the southwestern-most element of the array).

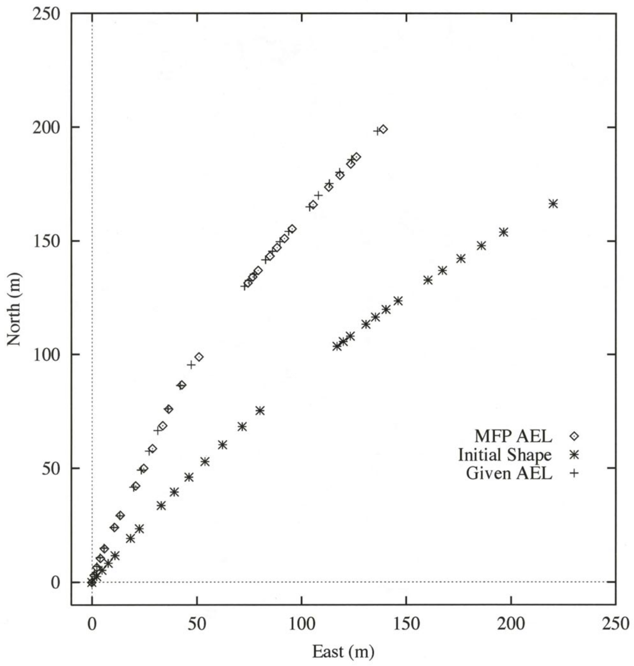

Figure 3. MFP array element position estimates obtained from processing the towed source data. Also shown are the initial array shape and given AEL.

Figure 3 shows the MFP AEL estimates obtained from processing the towed source data. Similarly, the MFP AEL results from processing the ship signature data are shown in Figure 4. In both figures, the initial array shape and given AEL also are indicated. The MFP AEL results are very close to the given array shape.

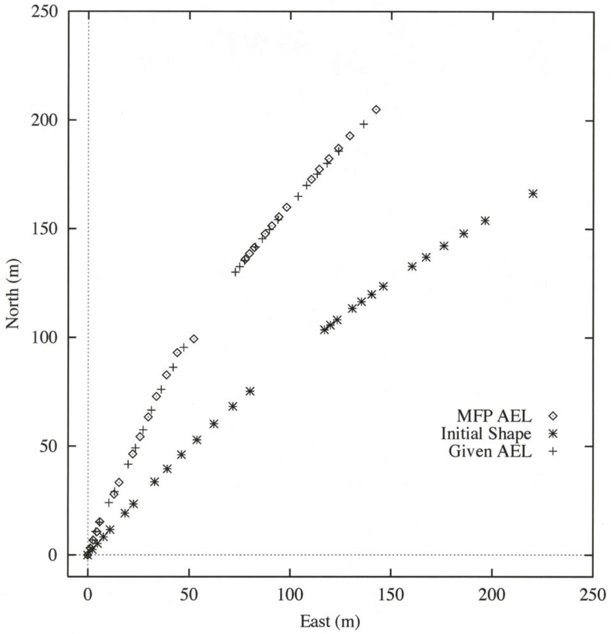

Figure 4. MFP array element position estimates obtained from processing the ship signature data. Also shown are the initial array shape and given AEL.

IV. PARAMETRIC REPRESENTATION OF ARRAY SHAPE

The optimization algorithm used to obtain the results in Sect. III directly perturbed the individual array element positions. Although effective, a more general approach was desired that could be extended to include estimation of both geometrical parameters (e.g. array shape, source range and depth) as well as environmental parameters (e.g. water column and seafloor sediment sound speed). Thus, a simple parametric approximation to the array shape along with a genetic algorithm (GA) global search strategy was explored [7].

In this case, a parabolic shape for the array was used with the amplitude and orientation of the parabola needing to be estimated along with the range and depth of the source. A comparison between the parametric model and the given array element positions for AODS-N is shown in Figure 5. As indicated, a parabola with 15 m bow represents the actual array shape well.

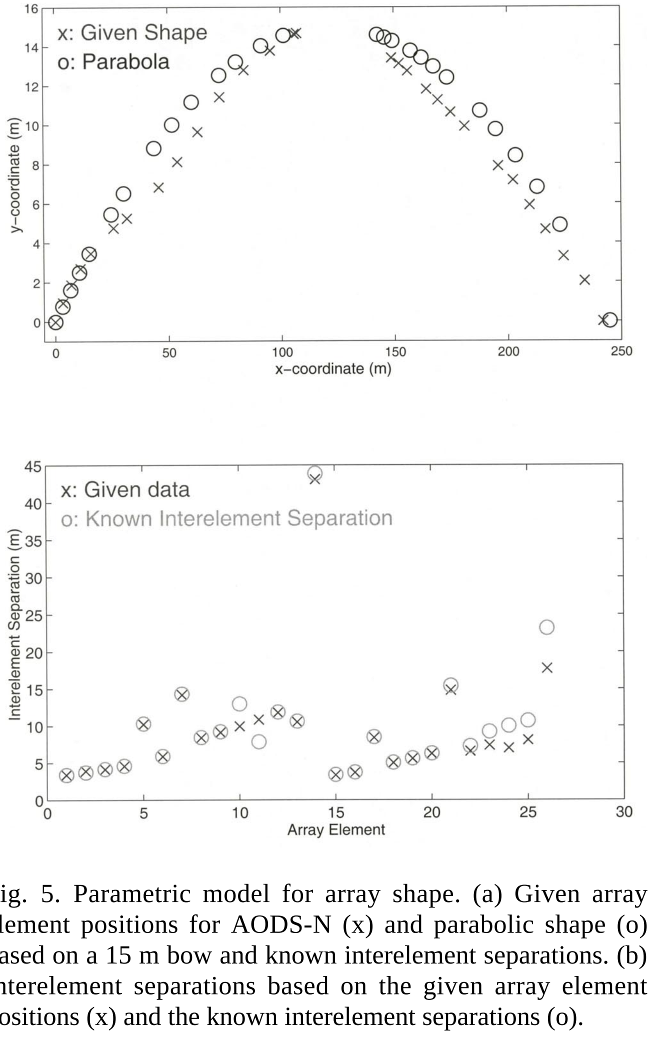

Fig. 5. Parametric model for array shape. (a) Given array element positions for AODS-N (x) and parabolic shape (o) based on a 15 m bow and known interelement separations. (b) Interelement separations based on the given array element positions (x) and the known interelement separations (o).

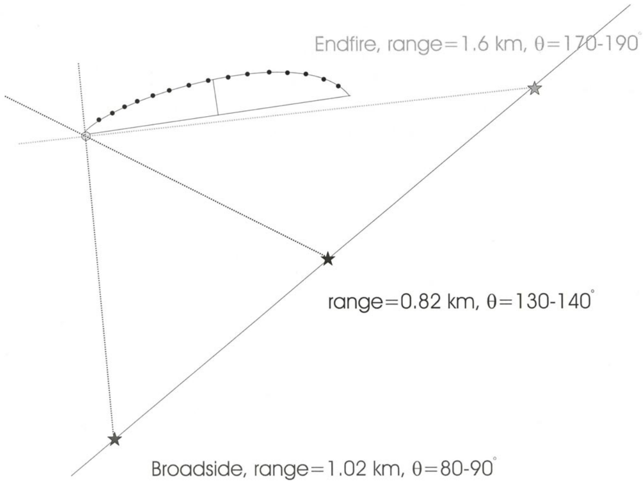

Fig. 6. Geometry for AODS-N array and Event S5 source tow track.

The GA parametric array shape approach was applied to three regions of the Event S5 source tow data. As shown in Figure 6, these represented broadside, near 45°, and endfire geometries with respect to the AODS-N line of bearing. All three yielded estimates for both amplitude and orientation of the parabolic approximation to the array shape that were very close to the known values. In addition, the range and depth of the source were localized correctly.

V. SUMMARY

The radiated signatures of ships transiting through an area can be used as natural sources of opportunity for the estimation of array element locations (AEL) and waveguide environmental parameters. Using a full-wave model of shallow water acoustic propagation, a matched field processing approach for AEL was demonstrated with horizontal line array data from SWellEx-96. The optimization algorithm directly perturbed the individual array element positions. Although effective, a more general approach was desired that could be extended to include estimation of both geometrical parameters (e.g. array shape, source range and depth) as well as environmental parameters (e.g. water column sound speed structure, bathymetry, and seafloor geoacoustic characteristis). A simple parametric representation of the array shape along with a genetic algorithm global search strategy then was defined. A parabolic shape with 15 m bow represented the actual array shape well. Using the GA search strategy with parameterized array shape, source tow data from broadside, near 45°, and endfire geometries was analyzed and yielded estimates of the array shape that were close to the known values.

ACKNOWLEDGMENTS

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