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A TECHNIQUE TO ESTIMATE THE THREE DIMENSIONAL DIRECTIONALITY OF UNDERSEA AMBIENT NOISE

R.A. WAGSTAFF, E.K. HOLMSTROM†, B.A. BLUMENTHAL** and R.W. TOWNSEND†

Naval Oceanographic and Atmospheric Research Laboratory, SSC, MS 39529, U.S.A.
†Systems Integrated, 10635 Scripps Ranch Blvd., San Diego, CA 92131, U.S.A.
**Office of Naval Research Det., SSC, MS 39529, U.S.A.

ABSTRACT

A technique has been developed to estimate the three dimensional character of the undersea ambient noise field from beam noise data acquired by a horizontal line array. Results are presented wherein measured beam noise data for several array headings and knowledge of the array's beam response patterns were used to estimate the 3-D noise field.

INTRODUCTION

Several algorithms and techniques have been developed to estimate the horizontal directionality of ambient noise from horizontal line arrays. In most cases, the 2-D representation of the array beam pattern is adequate to accurately estimate the horizontal directionality /1/. When significant amounts of the noise are distributed at angles well off the zero elevation angle, use of the 3-D structure of the beam patterns and a priori information about the noise vertical arrival structure greatly improve the estimate /2/. Unfortunately, the 3-D noise field is not estimated by this latter technique, only the 2-D horizontal directionality. The algorithm described herein uses an iterative technique and the 3-D conical nature of the beam response patterns to estimate the 3-D ambient noise directionality. The algorithm is described and results from actual at-sea measurements are presented.

BACKGROUND

The line array, because of its relatively low cost and ease of deployment, is often used to measure the undersea ambient noise. Furthermore, the towed horizontal line array with its added advantage of being highly mobile has achieved a high degree of utilization by researchers. The major disadvantage of the line array is that its ability to distinguish the direction a sound is coming from is limited to the angle the sound arrival makes with the axis of the array. It cannot uniquely determine the spherical coordinates of the arrival direction. The ambiguity in angle of arrival that results describes a cone with the apex at the center of the array and the center axis oriented along the axis of the array. The half angle of a cross section of the cone apex angle is equal to the arrival angle of the sound relative to the array axis. This is illustrated by the representation of the towed array in Fig. 1 and the superimposed 3-D beam response patterns.
The 3-D nature of the line array’s sound reception characteristics in the ocean is illustrated by Fig. 1. The complexity is further illustrated by Fig. 2 in which the noise sphere is represented as a flat surface and the beam response “footprints” of both a horizontal line array on a heading of 270° with a few degrees of array tilt (solid curves) and a vertical line array (dashed horizontal lines) have been superimposed. The footprints of the vertical array's beams follow lines of constant elevation angle. Since they have no azimuth angle dependence, data from a vertical array cannot be used to estimate the azimuthal dependence of the ambient noise. On the other hand, the footprints of the horizontal line array have both elevation and azimuth angle dependencies. Therefore, it should be possible to estimate both the azimuth and the elevation angle dependence of the noise from horizontal line array data when measurements are made on several different headings. A slight tilt of the array, as illustrated in Fig. 2, is desirable to eliminate upward-downward ambiguities. Some degree of tilt is generally inevitable in the measurement process.

Figure 1 Representation of a towed horizontal line array measuring undersea ambient noise.

Figure 2 Representation of a spherical noise field $N(\Theta, \Phi)$ and the conical footprints of the vertical line array (VLA) and tilted horizontal line array (HLA) on a plane surface.
The horizontal line array can determine the arrival angle $\beta$ of a signal relative to the axis (or line) of the array, but it cannot determine the absolute orientation in space. Hence, all orientations give the same response as long as the arrival angle relative to the array axis is the same. The resulting beam response pattern is conical, which intersects a concentric sphere in a circle as illustrated in Fig. 3. The noise field, on the other hand, is more naturally described in terms of spherical coordinates. The mathematical representations of the conical beams of the line array and the spherical nature of the noise field are basically incompatible. This incompatibility must first be overcome before an efficient algorithm can be developed to estimate the spherical noise $N(\theta, \phi)$ from conical beam noise data. This incompatibility is overcome by the following equation which transforms the noise power at spherical angles $\theta$ and $\phi$ into noise at the conical angle $\beta$:

$$
\beta = \cos^{-1}\left(\cos \theta \cos \phi \cos \alpha + \sin \left[\cos^{-1}\left(\cos \theta \cos \phi\right)\right]\sin \alpha \sin \left[\tan^{-1}\left(\sin \phi / \cos \phi \sin \theta\right)\right]\right)
$$

The estimation of $N(\theta, \phi)$ is an iterative one that begins with assuming a noise field $N_0(\theta, \phi)$. The simplest possible form is a constant, which corresponds to an isotropic noise field e.g. $N_0(\theta, \phi) = C$. Next $N_0(\theta, \phi)$ is convolved with the beam patterns of the array, using equ. (1), to get estimates of the beam noise. The differences between the measured and estimated beam noise data are used to either add noise to or subtract noise from $N_0(\theta, \phi)$ at the appropriate locations $\theta$ and $\phi$. When this has been done for all beams and all array headings, an improved estimate $N_i(\theta, \phi)$ has been created. This process of convolution and noise field modification is continued until the differences fall below a predetermined threshold, and then the final $N_i(\theta, \phi)$ is accepted as the best estimate of $N(\theta, \phi)$.

**RESULTS**

Beam noise data from a line array on different orientations in the undersea
ambient noise field were processed by the 3-dimensional noise field estimation algorithm. The results are presented in Fig. 4. The noise levels as a function of elevation angle $\theta$ and azimuth angle $\phi$ are plotted in gray scale contours with the level increasing with darkness. The horizontal directionality of the noise $N(\theta)$ is included as a trace on a rectangular plot below. $N(\theta)$ is the quantity that a 2-dimensional estimation algorithm would attempt to generate. In the case of the 3-D field, $N(\theta)$ is obtained by merely summing over all $\phi$ at a given $\theta$. The curves in the rectangular plot at the right of Fig. 4 are vertical profiles of the total noise $N(\phi)$ and of the noise in two small azimuthal sectors, one in a direction of high level noise ($\phi_2 = 295$ deg) and one in a direction of low level noise ($\phi_1 = 150$ deg). The vertical profile of the total noise is generally obtained from measurements by a vertical line array. In this case, it was obtained by summing over all $\theta$ at a given $\phi$. The other two vertical profiles are for sectors that could not be measured by either a vertical line array or a horizontal line array. In fact, the measurement of those profiles would normally require a high resolution volumetric array, something that presently does not exist.

**SUMMARY/CONCLUSIONS**

A technique for using horizontal line array beam noise data measured on multiple headings of the array has been developed. It utilizes an iterative technique that compares measured beam noise data with corresponding results obtained from convolving the beam noise patterns with an estimate of the 3-D noise field to guide modifications of the noise field estimate. Once the final estimate is obtained, it is then possible to investigate characteristics of the noise field that are essentially invisible to the array that acquired the original beam noise data.

**References:**