MULTIPLE SOURCE LOCALIZATION IN AN UNCERTAIN OCEAN ENVIRONMENT

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1. OVERVIEW

This paper considers simultaneous localization of multiple ocean acoustic sources when properties of the environment (water column and seabed) are poorly known. A Bayesian focalization approach [1, 2] is developed in which the locations and complex strengths (amplitude and phase) of the sources together with uncertain environmental properties and noise variance are all considered random variables comprising the model of unknown parameters. The posterior probability density (PPD) for the model combines information from measured acoustic, formulated in terms of the likelihood function, and by prior information (typically parameter search bounds). The goal then is to maximize the PPD over all parameters to extract the most probable set of source locations.

PPD maximization can be carried out analytically for the source strength and variance parameters by setting partial derivatives of the likelihood to zero. This leads to a linear system of complex equations which is even- or over-determined provided the number of data is greater than or equal to twice the number of sources, and hence is amenable to standard least-squares solution. Maximizing the PPD over the environmental parameters cannot be performed analytically, and is carried out here using a numerical optimization algorithm, adaptive simplex simulated annealing [3], with the analytic solution for source strengths and variance applied for each model realization considered in the optimization process.

2. EXAMPLES

The multiple-source localization procedure outlined above is demonstrated with a synthetic example illustrated in Fig. 1. The geoacoustic parameters include the thickness h of an upper sediment layer with sound speed c_s, density ρ_s, and attenuation α_s, overlying a semi-infinite basement with sound speed c_b, density ρ_b and attenuation α_b. The water-column sound speed profile is represented by four unknown sound speeds c_1-c_4 at depths of 0, 10, 50, and D m, where D is the water depth. All of these environmental parameters are considered unknown with prior information consisting of uniform distributions over wide bounds (true parameter values and prior bounds are given in Table 1). Two acoustic sources are present, one at 7-km range and 4-m depth (referred to as the shallow source), and the other at 5.4-km range and 50-m depth (the deep source). Acoustic fields from these two sources are computed at a frequency of 300 Hz at a 24-sensor vertical line array (VLA) using a normal mode propagation model.

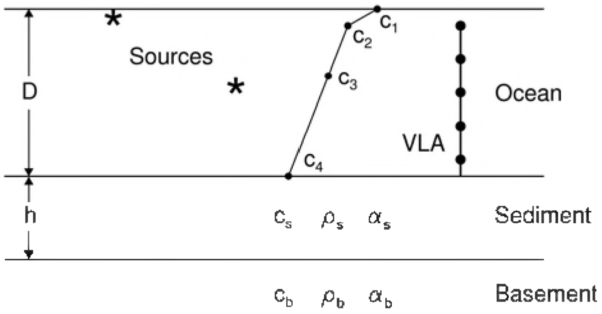

Figure 1. Schematic diagram of the geometry of the two-source localization problem, indicating unknown environmental parameters.

For the study carried out here, acoustic data are considered at five signal-to-noise ratios (SNRs) for the deep source. The SNR of the shallow source is either the same as that of the deep source (Fig. 2) or 12 dB higher than that of the deep source (Fig. 3). For each SNR combination, 50 different noisy data sets were generated and inverted for source locations. To demonstrate the advantage of optimizing over uncertain environmental parameters, focalization results are compared to two cases of localization for fixed environments where the environmental

Parameter & Units	Value	Prior Bounds
SSP:		
D (m)	130	[128, 135]
c_1 (m/s) @ 0 m	1520	[1515, 1525]
c_2 (m/s) @ 10 m	1517	[1510, 1520]
c_3 (m/s) @ 50 m	1515	[1510, 1520]
c_4 (m/s) @ 130 m	1510	[1505, 1515]
Seabed:		
h (m)	9.0	[0, 30]
c_s (m/s)	1494	[1450, 1600]
c_b (m/s)	1529	[1500, 1650]
ρ_s (g/cm^3)	1.38	[1.0, 1.7]
ρ_b (g/cm^3)	1.52	[1.5, 2.2]
α_s (dB/λ)	0.02	[0, 1]
α_b (dB/λ)	0.22	[0, 1]

Table 1. True values and uniform prior bound widths for environmental parameters of the synthetic test case.

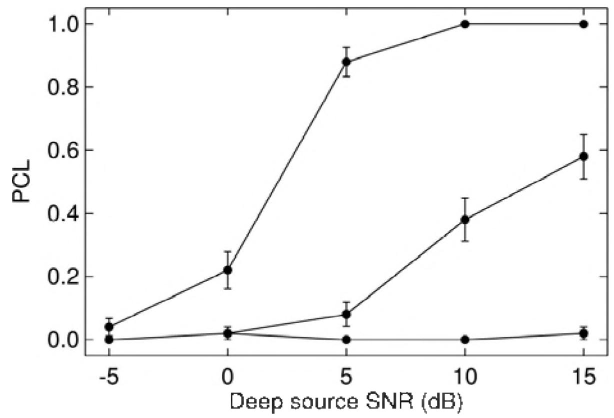

Figure 2. Probability of correct localization for random environmental realizations (lower curve), optimization over wide environmental bounds (middle curve), and exact environment (upper curve) as a function of SNR for the deep source. The shallow source has the same SNR as the deep source in all cases.

parameters correspond to either a random realization from the prior distribution (representing the actual environmental uncertainty) or to the true parameters (i.e., perfect environmental knowledge). The results are quantified in terms of the probability of correct localization (PCL), which is defined as the fraction of localizations achieving mean absolute depth and range errors of less than 10 m and 300 m, respectively, for both sources. One standard deviation binomial uncertainties are indicated as error bars for the PCL values in Figs. 2 and 3.

Figures 2 and 3 show the level of environmental uncertainty assumed in this example essentially precludes localizing the two sources using standard methods, with near-zero PCL values for random environmental realizations at all SNRs.

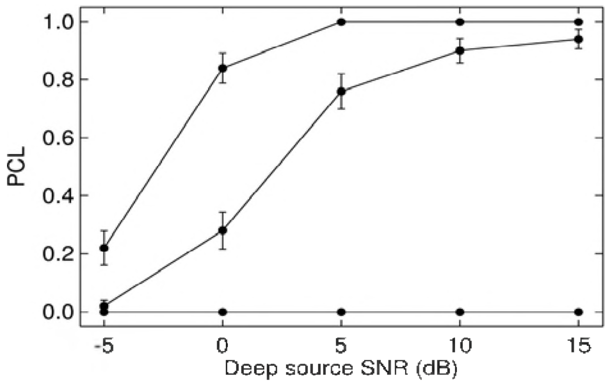

Figure 3. Probability of correct localization for random environmental realizations (lower curve), optimization over wide environmental bounds (middle curve), and exact environment (upper curve) as a function of SNR for the deep source. SNR of shallow source is 12 dB higher than that of the deep source in all cases.

However, optimizing over the unknown environment via focalization provides much better localization results for all but the lowest SNRs, with PCL values approaching those for the true environment for the higher SNR cases in Fig. 3 (localization results are generally better in Fig. 3 than Fig. 2 because of the higher SNR for the shallow source).

Finally, it is interesting to consider how the presence of the shallow source affects the ability to localize the deep source, given focalization over the unknown environment. For instance, to achieve PCL = 0.5 for two source with equal SNR, Fig. 3 shows an SNR of approximately 12.5 dB is required. When the SNR for the shallow source is 12 dB higher than for the deep source, Fig. 3 shows the deep-source SNR required for PCL = 0.5 is about 2 dB. For comparison, single-source localizations with only a deep source present (not shown) required an SNR of 1 dB for PCL = 0.5.

3. SUMMARY

This paper developed a Bayesian focalization approach to multiple source localization in an uncertain environment that made use of analytic solutions for the amplitude and phase of the unknown sources. Synthetic examples considered indicated a substantial improvement in probability of correct localization over localizations with fixed (incorrect) environmental parameters.

REFERENCES

[1] Collins, M. D., and W. A. Kuperman (1991). Focalization: Environmental focusing and source localization, J. Acoust. Soc. Am., vol 90, 1410-1422.

[2] Dosso, S. E. and M. J. Wilmut (2002). Comparison of focalization and marginalization for Bayesian tracking in an uncertain ocean environment, J. Acoust. Soc. Am., vol 125, 717-722.

[3] Dosso, S. E., M. J. Wilmut and A. L. Lapinski (2001). An adaptive hybrid algorithm for geoacoustic inversion, IEEE. J. Ocean. Eng., vol 26, 324-336.