Passive Broadband Source Localization in Shallow-water Multipath Acoustic Channels

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Abstract

This paper addresses the problem of direct-path passive broadband localization of a shallow-water acoustic source with a sparsely distributed set of sensors in the presence of uncertain multipath propagation. The classical approach to broadband source localization with sensors spaced many wavelengths apart involves time delay estimation (TDE) via general cross-correlation (GCC) methods. In shallow-water scenarios, however, multipath arrivals yield spurious peaks in cross-correlation outputs resulting in anomalous estimates of source location. In this paper, cross-correlations are normalized by an expected direct-path delay and geometrically averaged over multiple array orientations in order to disambiguate multipath returns from direct-path arrivals. In shallow-water channels, this allows for more robust estimates of the inter-sensor time delay due to direct-path propagation. Simulation results indicate a significant improvement in source localization performance over GCC methods operating in multipath environments.

1 Introduction

• GCC methods are traditionally used for source localization via time delay estimation (Knapp 1976, Carter 1987).
• Originally developed for non bottom-interacting, deep-water scenarios, GCC methods typically assume only direct-path propagation between the source and receiver is present.
• GCC is capable of performing well in noisy environments, however, in shallow-water scenarios, it is not as robust to multipath propagation (Champagne 1996).
• Matched field processing (MFP) allow for multipath environments to be incorporated into the propagation model (Bucker 1976).
• A drawback of MFP is that it is not robust to errors in assumed environmental parameters which can be commonly made in such complex propagation conditions (Gingras 1989).
• In this work, the multipath arrivals will be treated as nuisance components and we focus on estimating the time lag that corresponds to the predictable direct-path from source to receiver. This will be accomplished by using a rotating baseline array to combine cross-correlograms from multiple array orientations.
• Cross-correlograms will be normalized by their direct-path time delay, then geometrically averaged across array orientation.
• This process averages out peaks in cross-correlation due to multipath return arrivals at different elevation angles and allows for more robust estimation of the direct-path time delay.

2 Signal Model

• The direct-path model assumed in GCC methods is generalized to suit the problem of estimating the direct-path time delay in the presence of unwanted multipath arrivals.
• Consider a two element sensor array in a shallow-water channel. The received signals at sensors 1 and 2 are given by

$$x_1(t) = x(t) * h_1(t) + n_1(t)$$
$$x_2(t) = x(t - \tau_0) * h_2(t) + n_2(t)$$

• In comparison the above model, the classic direct-path model assumes that \( h_1 = h_2 = 1 \). GCC methods when applied to the above model often give spurious estimates of the direct-path delay because of the multipath terms.

3 Multiple Orientation Geometric Average Algorithm

• Without loss of generality, assuming the source is in the far field and at zero elevation, the relative delay of the direct-path arrival is given by

$$\tau_\alpha(\theta, \alpha) = \frac{D}{2c} \sin(\theta + \alpha)$$

• The multipath structure can be exploited by shifting the cross-correlation output at different array orientations by the predictable direct-path time delay and taking the geometric average.

$$\Psi_M(\epsilon, \theta) = \frac{1}{m} \sum_{i=1}^{m} \Psi_G(\epsilon - \tau_\alpha(\theta, \alpha))$$

• Geometric average is computed for a set of hypothesized source positions and evaluated at the zero time-lag.
• The bearing estimate is thus given by

$$\hat{\theta} = \arg \max_\theta \Psi_M(0, \theta)$$

4 Simulation Results

• A simulation modeling a shallow-water, isovelocity waveguide with the method of images is presented.
• Simulation Parameters
  • 2 kHz linear frequency modulated waveform centered at 2 kHz
  • Range independent waveguide with the bottom 50 meters
  • Source positioned at 20 meters depth and a relative bearing of 60° and 45°

GCC Results

• GCC-ML vs. GCC-PHAT

Multiple Orientation Geometric Average Results

• Multiple orientation geometric average over 18 100 increments.
• Bearing estimate is given by the maximum.

5 Conclusion

• Simulation shows that multipath environments, such as those found in shallow-water, often lead to erroneous time delay estimates when using traditional GCC localization techniques.
• By using a rotating array to discriminate multipath arrivals at different elevation angles from the direct-path, a more robust estimate of source bearing in a multipath environment can be made.
• The channel does not have to be appropriately modeled as is the case with MFP techniques.


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