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Robust Control of Sound Field in an Ocean Waveguide

Jeasoo Kim[1 †], and Gihoon Byun[2] ([1]Korea Maritime and Ocean Univ., [2]Ocean Science and Technology School-Korea Maritime and Ocean Univ.)

1. Introduction

The control of sound field is a very useful tool and an active research area in various fields of acoustics. The control of sound field implies the manipulation of the spatial sound field, not in temporal time series such as noise cancellation, and it includes beamforming, focusing, nulling, and steering beam and foci. In various fields of acoustics, the terms for methodology vary, but the principle is based on the constructive and destructive interferences of sound emitted from spatially distributed sources and boundaries.

In this paper and presentation, we collect and overview the state of art methods for manipulating the sound field in an oceanwave guide from the view point of underwater acoustician.

First, we start with an acoustic emission from a single sound source in an ocean waveguide, and extend it to the concept of beam forming and steering. Secondly, the concept of Time-Reversal Mirror(TRM) is introduced to focus the sound spatially as well as temporally. Consequently, it is demonstrated that the null in sound field, where the sound field from multiple sources are destructively interfered so as to form a null sound field, can be steered under certain conditions. Finally, the issue of robust focusing and nulling is presented.

2. Control of Sound Field

2.1. Overview of Time-Reversal Mirror

Time-Reversal (TR) processing has been demonstrated in various fields such as optics, ultrasonics, and underwater acoustics. In TR processing, a transmitted probe signal is received at array of each source-receive elements, often referred to as a time-reversal mirror (TRM), and the received signals are time-reversed to be backpropagated. If the propagation medium is static, TR processing results in a coherent acoustic focusing at the probe source location using Eq.(1).

$$P(\vec{r}) = \sum_{i}^{N} G^{*}(\vec{r}_i|\vec{r}_{ps})G(\vec{r}|\vec{r}_i) \qquad (1)$$

$G(\vec{r}_i|\vec{r}_{ps})$ represents the received acoustic field at the i th TRM element from the probe source location $\vec{r}_{ps}$. Superscripts $(\ )^{*}$ denotes complex conjugation.

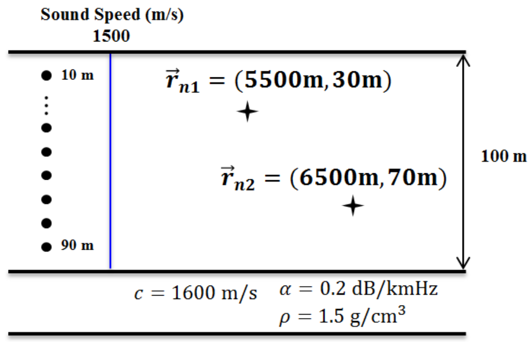
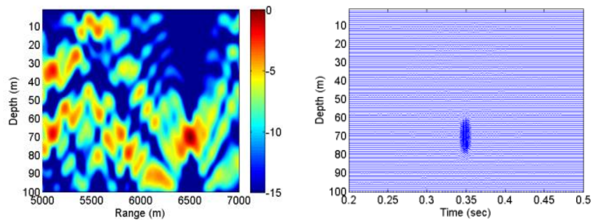


Fig. 1 Description of Pekeris waveguide for the numerical simulation.

When the time-reversed received signal at the array is backpropagated, the signal converges back to the probe source location where the signal was generated as depicted in Fig.2.



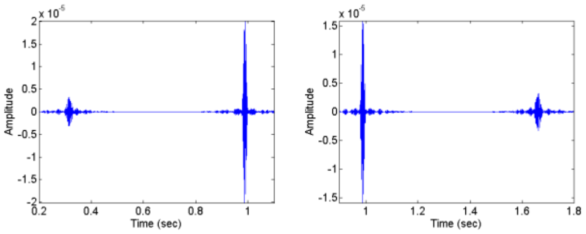
(a) Spatial focusing (b) Temporal focusing

Fig. 2 TRM simulation results for 20-ms at 300-Hz. The probe source is at 70-m depth and 6500-m range.

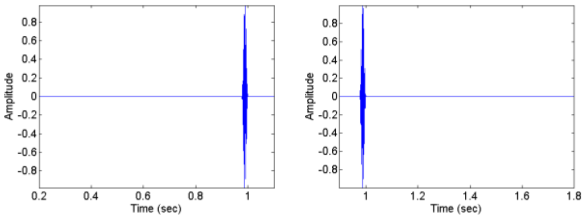
2.1. Adaptive Time-Reversal Mirror

In adaptive signal processing, minimum variance distortionless response (MVDR) is well known for minimization of the output power of variance subject to a constraint on the look direction. This adaptive method has been applied to TR processing which is called adaptive time-reversal mirror (ATRM) in an ocean waveguide[1]. For the purpose of simultaneous multiple focusing with distortionless reponse in TR processing, ATRM has been extended based on linearly constrained minmimum variance (LCMV)[2].

Figure 3 shows the comparison between superpostion and LCMV method for simultaneous multiple foucisng in Fig.1. As seen in Fig.3(a) and (b), unwasted signal which is equal to the crosstalk in the view of multiuse communications can exit due to the interference between signal vectors from two probe sources. In Fig.3(c) and (d), the notable result is that the pulse compression can be achieved without interference at the both locations $\vec{\boldsymbol{r}}_{n1}$ and $\vec{\boldsymbol{r}}_{n2}$ using LCMV method.



(a) Time series at $\vec{r}_{n1}$ in superposition (b) Time series at $\vec{r}_{n2}$ in superposition



(c) Time series at $\vec{r}_{n1}$ in LCMV (d) Time series at $\vec{r}_{n2}$ in LCMV

Fig. 3 Simulated back-propagated time series.

2.3. A Concept of Virtual Source Array

The main limitation of TR processing which requires a probe source for coherent focusing has been partially relaxed by a virtual source array (VSA) concept[3]. From a practical point of view, the method is propsed to get rid of the need of a probe source to implement TR porcessing under proper conditions. A location beyond the VSA is selected as seen in Fig.3, and simple time-delay beam-steering is required in the near field limit assumption. This calcaulated time-delay between VSA and a selected location is applied to synchronized transfer function between TRM and VSA so that the field is steered to the selected location where the transfer function is not known a priri. Figure 4 shows the demonstration of the VSA concept in waveguide conditions as shown in Fig.3.

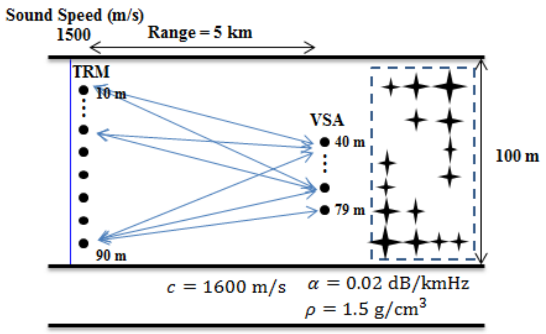


Fig. 4 The schematic of the VSA concept.

LCMV method can be applied to the conventional VSA concept to accomplish simultaneous multiple focusing without a PS. For the numerical simulation, arbitrary two locations $\vec{r}_{n1} = (5200\text{ m}, 50\text{ m})$ and $\vec{r}_{n2} = (5300\text{ m}, 60\text{ m})$ are selected.

Figure 6 shows that the adaptive approach can be applied to not only conventional TR processing but also the VSA concept which results in the simultaneous multiple focusing without a probe source, implying considerable adavantages for application of TR processing. Also, another possible application can be underwater communcations[4,5] in complex media.

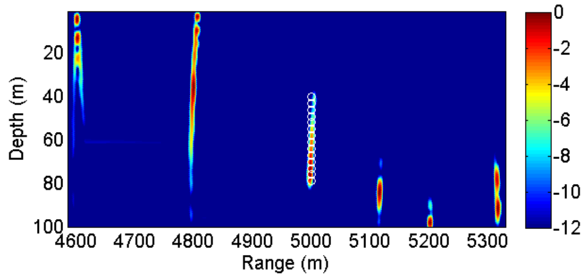
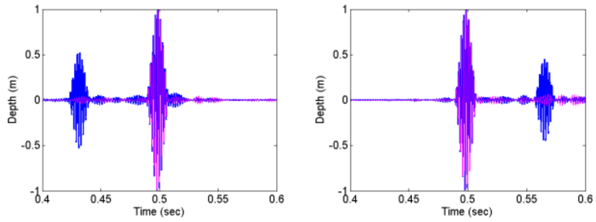


Fig. 5 Simulated coherent focusing using a VSA concept in TRP at 100-m depth and 5200-m range.



(a) Time series at $\vec{r}_{n1}$ (b) Time series at $\vec{r}_{n2}$

Fig. 6 The result of multiple focusing in the VSA concept using superposition(blue) and LCMV(majenta).

3. Summary

In this paper, the methods to control the sound field in an ocean waveguide are reviewed. TR processing has been explotied as the most effective way to control the sound field and extended to ATRM for simultaneous multipe focusing and nulling. Also, we introudce an algorithm for robust focusing without a probe source based on a VSA concept. It is demonstrated via numerical simulation that the sound field can be effectively controlled by presented methods.

References

1. J. S. Kim, H. C. Song, and W. A. Kuperman: J. Acoust. Soc. Am. **109** (2001) 1817.
2. J. S. Kim and K. C. Shin: J. Acoust. Soc. Am. **115** (2003) 600.
3. S. C. Walker, P. Roux, and W. A. Kuperman: J. Acoust. Soc. Am. **125** (2009) 3828.
4. Takuya Shimura, Yukihiro Kida, Mitsuyasu Deguchi, Yoshitaka Watanabe and Hiroshi Ochi: J. Appl. Phys. **54** (2015) 07HG02.
5. Takuya Shimura, Hiroshi Ochi, Yoshitaka Watanabe and Takehito Hattori: J. Appl. Phys. **49** (2010) 07HG11.