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Performance Analysis of Passive Time Reversal Communication Technique for multipath interference in shallow sea acoustic channel.

浅海域音響伝搬路における多重反射波干渉に対する位相共役通信手法の機能分析

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1. Introduction

The interference by time-varying and intense underwater acoustic multi-path is one of the most obstructive phenomena in underwater acoustic communication. Passive Time Reversal (PTR) communication techniques utilize the reciprocity of acoustic channels to converge the spread signals to the original one, and is considered one of the most effective methods to overcome multi-path interference as shown in many past studies [1]. It is recognized emprically that the large number of multi-path arrival could generally raise the demodulation result of PTR, however, its relationshp is rarely evaluated quantitatively.

In this paper, we investigate the efficiency of the PTR acoustic communication techniques for multi-path interference cancelation by applying our PTR scheme to synthetic datasets of horizontal acoustic communication in shallow water environment. Mainly, we focused on the relation between the Signal to Interference Ratio (SIR) and the Output SNR (OSNR) of demodulation result.

2. Passive Time-Reversal Communication

We have developed a PTR scheme for the horizontal acoustic communication in past studies [2]. In this study, we also applied the PTR+DFE scheme to demodulate acoustic signal. The transmitted signal is composed of Raised Root Cosine Filtered Pulse (RRCFP) and information signal of BPSK. The frequency band is 8kHz and the center frequency is 20kHz. We used the RRCFP record to estimate the green function between the source and each receiver for PTR processing.

3. Synthetic Datasets

The normal mode equation method [3] is used for the calculation of channel response of the synthetic datasets. The simulation model is shown in the **Fig.1**. The model environment is assumed as the shallow sea horizontal communication between fixed mounted a source and receiver array. The acoustic records are mainly composed of direct arrival and multiple reflections between the surface and the bottom of the water column. The direct arrival is assumed to be the reference signal to evaluate the intensity of multi-path interference and random noise.

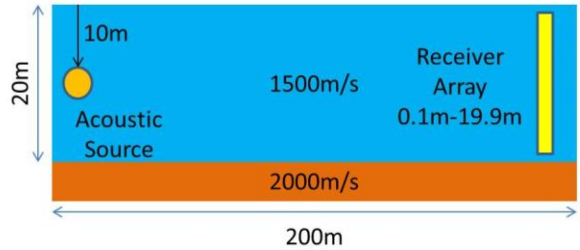

Fig. 1 Configuration of the simulation.

We applied the truncated Singular Value Decomposition (SVD) method [4] to decompose the direct arrival and the multiples for the calculation of the SINR of the record. Let X be a data matrix of acoustic wave-field record. The SVD of X is given by:

$$X = \sum_{i=1}^{r} u_i \sigma_i v_i^T \quad (1)$$

where superscript T indicates transpose, r is the rank of X, u_i and v_i are i th eigenvectors of XX^T and $X^T X$ respectively, and σ_i is the i th singular value of X. X is decomposed into each eigenvectors according to the coherency among time-series records of the receiver array. Eigenvectors with lower rank and large singular value correspond to the highly coherent wave-fields among receivers. Therefore, we applied time shift to each receiver's record to align the time front of direct arrival to raise the coherency as a preprocessing of SVD. After time shifting, the wave-field of direct arrival should be corresponding to lower ranks of singular values so we can extract direct arrivals X_D and multiples X_M by choosing a rank of direct arrival wave-field $m(m < r)$:

$$X_D = \sum_{i=1}^{m} u_i \sigma_i v_i^T, \quad X_M = \sum_{i=m+1}^{r} u_i \sigma_i v_i^T \tag{2}$$

An example of the result by decomposition is shown in **Fig.2**. Finally, the data matrix $\underset{\sim}{X}$ which we used for the analysis is acquired by controlling intensity of multiples as follows:

$$\underset{\sim}{X} = X_D + \alpha X_M + N \tag{3}$$

where α is a scalar value for amplitude adjustment to vary the SIR and N is the matrix of additive white Gaussian noise (AWGN).

4. Result & Discussion

Fig.3 and **Fig.4** shows the plots of SIR-OSNR and SNR-OSNR relation from the demodulation result with 100 channel 20cm equispaced receivers array. The colored lines describe difference levels of SNR and SIR respectively as shown in legends of figures. It should be noted that only the level of direct arrival is used for the calculation of SNR and SIR.

In lower SNR part, OSNR of the demodulation result improve with SIR decreasing. It shows that the energy of the multi-path is surely utilized to improve OSNR. The result of SNR=-10dB in Fig.3 shows that the improvement of OSNR is proportional to the intensity of multi-path. This characteristic is also observed in the lower SNR part of Fig.4. The gain from PTR would approximately be equivalent to the summation of SIR and the array gain. In high SNR part, improvement of OSNR of lower SIR datasets is gradually becoming duller than higher SIR datasets.

From Fig.3, OSNR could be seen as converged to a typical value arround 29dB with decreasing of SIR in each dataset. Especially high SNR datasets (SNR>20dB), OSNR is gradually decreasing with increasing of SIR. This would show the limitation of ability of convergence with PTR processing in this environment.

5. Conclusion

In this study, we tried to reveal the relation between PTR and multipath interference by quantitative analysis. As results, several characteristics are found:

1. PTR utilize the energy of multi-path efficiently. The improvement of OSNR would be proportional to the intensity of multipath signals.
2. There is a limitation of improvement of OSNR by PTR. This limitation should be dependent on the aquisition environment.

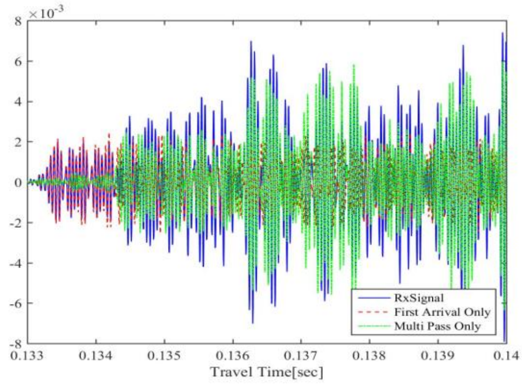

Fig. 2 Example of a decomposed by T-SVD (blue: received signal, red: extracted direct arrival signal, green: multiples.

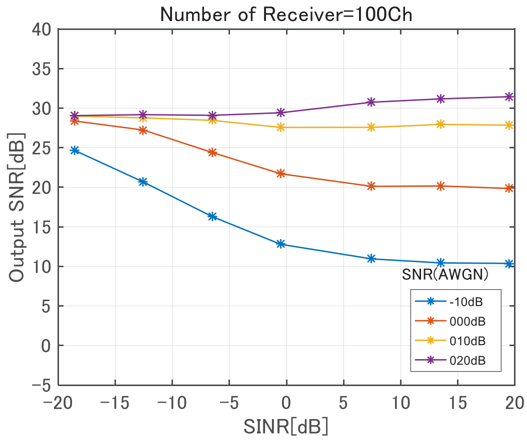

Fig. 3 SIR V.S. Output SNR

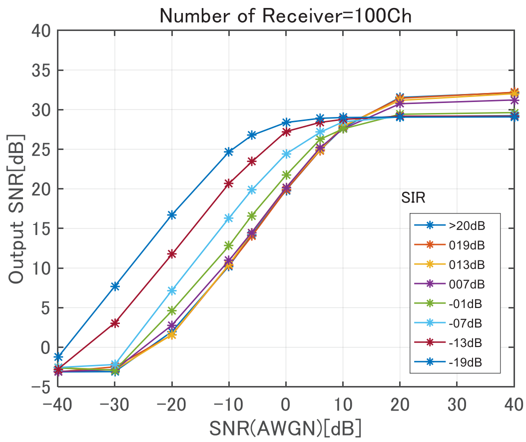

Fig. 4 SNR V.S. Output SNR

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