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A Relationship of Time Reversal and Multi-Channel DFE in Underwater Acoustic Communication

水中音響通信処理におけるタイムリバーサル処理と多チャンネル DFE の関係について

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1. Introduction

Underwater acoustic channel (UAC) is one of the most difficult environment for remote communications because of its time-varying response and severe multipath interference.

The time-reversal communication technique is one of the promising solutions for the multipath rich UAC. The "passive" time reversal (PTR) technique has been studied as an alternative solution for conventional multi-channel equalizers in highly coherent UAC. Generally, it is considered that PTR can utilize the energy of multipath to improve the quality of demodulated results[1)].

On the other hand, multi-channel decision-feedback equalizer[2)] (MDFE) is known as one of the conventional techniques in coherent UAC environment. Interestingly, according to a past numerical investigation[3)], it is also indicated that MDFE can also utilize the multipath to improve the resulted performances of equalization. Although the investigation was performed by a very simple ray-based-channel model, it indicates that there would be some relationship for PTR.

In this study, the relationship between the performance of PTR and MDFE in multipath-rich UAC is investigated. Both methods are applied to synthetic dataset for single-inupt/ multiple-output (SIMO) communication from a moving source in a shallow sea environment. The investigation is focused on the performance for utilization of the energy of multipath.

2. Synthetic Dataset

In this study, a comparison of the performances of PTR and MDFE to underwater acoustic SIMO communication problem is discussed. To investigate the performances, both methods are applied to synthetic dataset. The synthetic dataset is generated on the basis of normal mode theory including the Doppler effects caused by transmitter movement[4)]. The configuration of the normal mode simulation for a shallow sea problem is described in **Fig. 1**. The acoustic source moves horizontally during transmission. The signaling frame is composed of a chirp signal for the estimation of channel impulse response (CIR) and information signal modulated by bi-phase shift keying using single carrier modulation scheme. The estimated CIR by using pulse compression of the chirp signal is shown in **Fig. 2**. The information signal is sandwiched by two synchronization codes to estimate the compression and dilatation of the communication signal caused by Doppler effects.

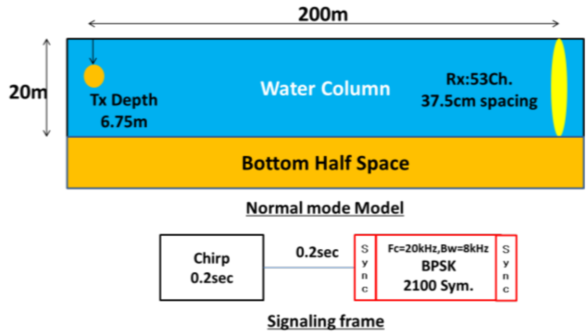

Figure 1 Acoustic Simulation model.

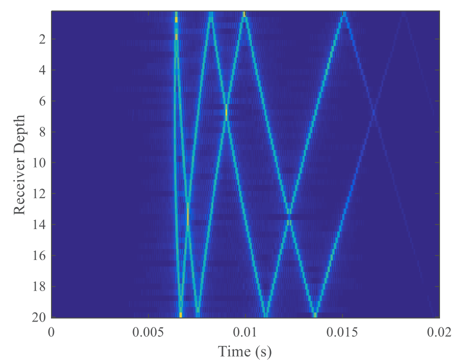

Figure 2 CIR of the acoustic model.

3. PTR and MDFE

We have developed a PTR scheme for horizontal acoustic communication in past studies[1,5)]. In PTR, the back-propagation process is realized by the cross-correlation between the received signal x_i and measured CIR h_i on the i^{th} receiver in time domain:

$$s_{PTR} = \sum_i \hat{h}_i \otimes x_i = \sum_i \left(\hat{h}_i \otimes h_i\right) * s = q * s \quad (1),$$

where, $\hat{h}_i$ is estimated CIR from the probe pulse, s is the transmitted signal, q is the q-function. If the PTR process works well, q-function are close to the delta function. In practical configuration of receiver array, it is difficult to realize such a perfect focusing

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(i.e. $q = \delta$) only with PTR. To remove the residual interference, a single-channel decision-feedback equalizer with short tap length is appended after the PTR process in our proposed method.

The PTR-DFE scheme is compared with a conventional least-mean-square based MDFE scheme[3] in this study. The n^{th} output of the MDFE is as follows:

$$y(n) = \sum_{i=1}^{N_{ch}} \sum_{l=a(a<0)}^{l=b(b>0)} F_{il}(n) x_i(n-l) e^{-j\theta_i} + \sum_{m=1}^{M} B_m(n) d(n-m) \quad (2)$$

where, y is the output of MDFE, x is the input signal in base-band, d is the decided data symbol, θ is estimated phase shift, F is the feedforward-filter weight, and B is the feedback-filter weight respectively.

The performances of both methods are evaluated by output signal-to-noise ratio (OSNR) of the demodulated symbols. If a diversity combining scheme can ideally combine the energy of multipath, the output result should be described as follows:

$$ESNR = \frac{E_{direct} + E_{multipath}}{E_{noise}} + AG,$$

where E_{direct} is the energy of direct path, $E_{multipath}$ is the energy of multipath, E_{noise} is the energy of ambient noise, and ESNR is the effective SNR for ideal processing. In ideal multi-channel processing, the array gain (AG) should be:

$$AG = 10\log_{10}(N_{ch}).$$

4. Results & conclusion

Fig. 3 shows the comparison between PTR and MDFE in various ENSR. The ESNR is varied by adding a white Gaussian noise to the dataset. The black dashed line shows the theoretical limitation of the processing, where [ESNR=OSNR]. In lower ESNR, the results of PTR improve accordingly to the theoretical limitation with increasing ESNR. It indicates that PTR utilizes the energy of multipath completely for the demodulation results. On the other hand, the results of MDFE drop below the theoretical limitation. In higher ESNR, results of both methods gradually converge to typical values. The difference between the results of PTR and MDFE at ESNR≒12.25dB pointed by an arrow in Fig.3 is about 4.5dB.

It is found that the feedforward filter of MDFE acts like PTR combine in this environment. The distribution of amplitude of the feedforward weights well describes the CIR as shown in **Fig. 4**. Considering Eq. (2), results show that MDFE utilize the energy of the multipath as long as the filter length covering the duration of multipath. In this case, the feed-forward filter covers the CIR in Fig.2 up to 0.0081s. The calculated ratio of total energy

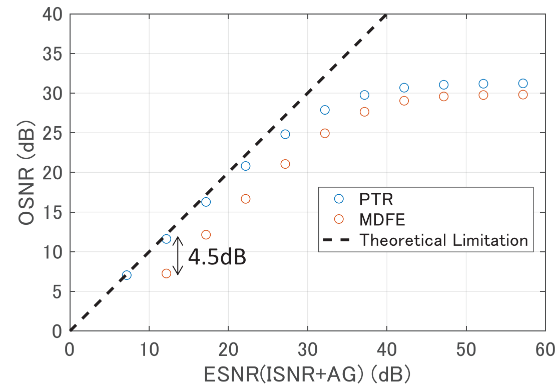

Figure 3 Comparisons in Effective SNR-OSNR

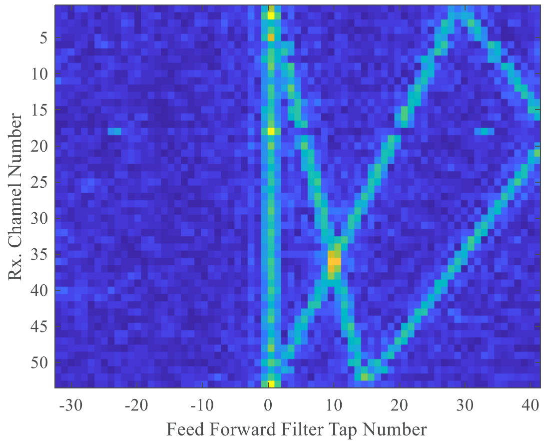

Figure 4 Feedforward filter taps of MDFE after demodulation.

of CIR to the energy of CIR after 0.0081s is about 4.7dB and this is well matched to the difference of the performance between PTR and MDFE.

In this study, the relationship between PTR and MDFE is investigated in shallow UAC. It is found that the feedforward filter of MDFE can act like a PTR combine in this environment. The difference of the performance would be derived by the covering length of multipath duration. It shows that PTR is capable of utilizing longer duration of multipath for demodulation results than MDFE.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP17K06977.

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