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Investigation of a channel tracking based time reversal processing for underwater acoustic communication

チャンネルトラッキングに基いたタイムリバーサル水中音響通信の検討

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1. Introduction

In digital communication, time reversal processing has been considered as a promising solution for the multipath rich underwater acoustic channels. However, the performance of a time reversal process can be limited because its ability for the reduction in inter-symbol-interference (ISI) is dependent on the time variation of the channel impulse response (CIR). To overcome such problems, time-reversal process is generally followed by a channel tracking based equalizers, i.e. decision feedback equalizer (DFE). Many studies for passive time reversal (PTR), which is realized by signal processing at a receiver side, have demonstrated remarkable performance as a single-input/multiple-output (SIMO) underwater acoustic communication (UAC) [1].

A past research for a mobile UAC using PTR followed by DFE (PTR=DFE)[2] has shown that demodulation of communication signals from sound sources moving at low speed is almost ideal, but its performance deteriorates with increasing the speed of the acoustic source movement. This degradation of the performance is caused by the differences of the CIR between the probe signal utilized for PTR processing and communication signal.

In this study, a channel estimation and update algorithms are introduced for the probe signals in PTR processing in order to make the PTR-DFE robust in mobile UAC. To investigate the performance of the communication signal processing, we simulated the mobile UAC data using the normal mode method and compared he demodulation performance with the conventional PTR-DFE.

2. CIR tracking based PTR-DFE

A SIMO wireless communication system is considered with M element receiver array. The received signal is assumed to be corrupted by additive white Gaussian noise (AWGN) $z(t)$. The time-series of the received signal $r_m(t)$ can be written as follows:

$$r_m(t) = h_m(t) * s(t) + z_m(t) \qquad (1)$$

where $s(t)$ is the transmitted signal, and $h_m(t)$ is the CIR between the transmitter and the m^{th} element of the receiver array. In PTR, the back-propagation process is realized by the cross-correlation between the received signal and the measured CIR. Then, the correlated signals are summed up along the receiver elements as shown in following equation:

$$\begin{aligned} s_{TR} &= \sum_{m=1}^{M} r_m(t) \otimes h_m(t) + z_m(t) \otimes h_m(t) \\ &\approx q(t) * s(t) \end{aligned} \qquad (2)$$

where, $q(t)$ is the channel q-function that can be equal to Dirac's delta function in ideal condition. In a conventional, the CIR h_m is measured by the probe pulse, such as the pulse compression result of frequency sweeps. Practically, $q(t)$ includes the interferential component called residual ISI as a result of imperfect PTR combining.

In a time-variant CIR environment, the PTR process cannot avoid the residual ISI because of the mismatch between the measured CIR and the actual CIR of information signals. To deal with this problem, the measured CIR for PTR combining should be replaced by the time-variant CIR prediction. Here, the channel model of a single receiver at k^{th} symbol in a symbolic form can be rewritten as follows:

$$r_k = \sum_n h_{kn} s_n + z_k \qquad (3)$$

where, n represents the time delay from the sampled time of k^{th} symbol, that is the time delay of the multipath.

Here, the problem is to estimate the CIR of the received information symbols in time-sequential form. The prediction of the received symbol $\hat{r}$ can be expressed using estimated CIR: $\hat{r}_k = \sum_n \hat{h}_{kn} s_n$.

The error function between the predicted and received symbol can be expressed as follows:

$$E_k = r_k - \hat{r}_k = r_k - \sum_n \hat{h}_{kn} s_n = r_k - \hat{\mathbf{h}}_k^* \mathbf{s} \qquad (4)$$

Then, we can calculate the updating parameter from

Eq. (4) by a steepest descent algorithm:

$$\hat{\mathbf{h}}_{k+1} = \hat{\mathbf{h}}_k + \mu E_k^* r_k \quad (5)$$

where, μ is a small step size parameter for regulating the CIR updating.

Figure 1 shows the block diagram of the channel tracking based PTR-DFE (CTB-PTR-DFE) scheme. The measured CIR is replaced by the estimated CIR by using the equation (5).

In this study, the CTB-PTR-DFE is applied to the synthetic dataset of moving source environment. The dataset is generated by the normal mode method for horizontally moving source problem (REF). The communication signal is modulated by single-career binary phase-shift keying. The performance of CTB-PTR-DFE method is compared with the performance of the conventional PTR-DFE method. In this short paper, the performance of each method is investigated by the output SNR (OSNR) of the equalized symbols. The OSNR is calculated as follows:

$$OSNR = 10\log_{10}\left(\sum_k |d_k|^2 \Big/ \sum_k |x_{est,k} - d_k|^2\right) \quad (6)$$

3. Result and Conclusion

Figure 2 shows the results of PTR-DFE and CTB-PTR-DFE. The horizontal axis on the panel shows the effective SNR (ESNR) including ideal gain as an optimal array processing which utilizes the energy of the all multipath for the equalization. The black dashed line shows the theoretical limitation where ESNR=OSNR.

In low speed of source movement, the result of each method shows almost ideal performance that the OSNR improves accordingly to the theoretical limitation. Then, in high ENSR dataset, the improvement of OSNR is saturated. The result of the conventional PTR-DFE is gradually deteriorated with increasing the source speed. On the other hand, the result of CTB-PTR-DFE is comparably stable to the increment of the source speed.

As a result, the performance of PTR-DFE for mobile UAC was improved by using the channel tracking algorithm as expected. The channel tracing algorithm used in this study is based on a single channel LMS updater. More improvement can be expected by using more advanced algorithms.

Acknowledgment

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References

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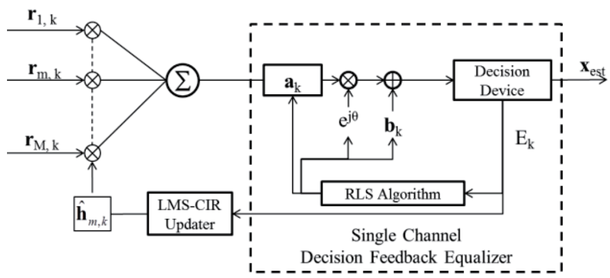

Fig. 1 Block diagram for a CIR tracking based PTR-DFE scheme. The estimated CIR is used for the PTR processing.

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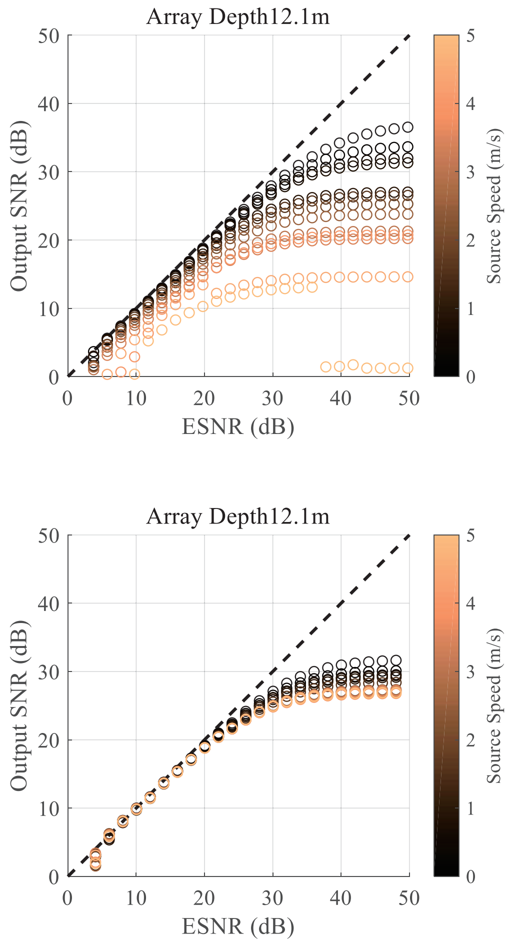

Fig. 2 The comparison of the performance of conventional PTR-DFE (upper) and CTB-PTR-DFE (lower). The color of markers in each panel shows the speed of the horizontal movement of the acoustic source.

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