Underwater acoustic communication using vector sensor in KOREX-17

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***Abstract*—Sound propagating through shallow-water waveguide undergoes inter-symbol interference (ISI) by multiple interactions with sea surface and bottom interfaces. Time reversal techniques using an array of spatially separated receivers have been widely used to reduce the effect of ISI. However, the time reversal method requires a large-size receiver array to improve the communication performance, which results in the degradation of space efficiency. The vector sensor measures acoustic pressure signal as well as x, y, and z-components of the particle velocity at a single point, and these signals can be used as a single-input multiple-output system (SIMO) for underwater acoustic communication. An underwater communication experiment using a vector sensor was made as part of the Korea Reverberation Experiment (KOREX-17) on May 24-25, 2017 in shallow water at location 34° 43′ N, 128° 39′ E. The communication results show that proposed technique(the block-based time reversal technique using the vector sensor) is useful in the time varying shallow water.**

Keywords—Acoustic vector sensor; Block-based time reversal; Single Input Multiple Output

I. Introduction

Underwater acoustic communication presents a challenging problem arising from the environmental properties of underwater acoustic waveguides. Acoustic waves propagating through shallow-water channels experience multiple interactions with the sea surface and ocean bottom. This causes a significant, time-varying delay spread called ISI (inter-symbol interference) [1]. The presence of ISI significantly degrades the communication performance [2], [3]. In addition, sea-surface or platform movement produces time-varying channels exhibiting relatively short coherence time and a large Doppler spread [4], [5].

Time reversal techniques that use an array of spatially separated receivers have been developed to address the difficulties in communication caused by multipath channels. The time reversal process improves communication performance by reducing ISI and increasing the signal-to-noise ratio (SNR) [6], [7]. As the distances between the receivers and the number of receivers increase, the communication performance improves. However, this causes the deterioration of spatial efficiency. Therefore, it may be difficult to use this technique in smaller underwater communication systems such as autonomous underwater vehicles or ad hoc underwater networks.

In recent years, the physics of sound propagation in the ocean have been investigated in terms of acoustic vector quantities such as the acoustic particle velocity or acceleration [8]. The utilization of these vector quantities has a range of applications, including sound source tracking and target detection. The vector sensor measures acoustic pressure signal as well as x, y, and z-components of the particle velocity at a single point, and these signals can be used as a single-input multiple-output system (SIMO) for underwater acoustic communication.

In this study, an underwater communication experiment using a vector sensor was made as part of the Korea Reverberation Experiment (KOREX-17) in time varying shallow water. The communication results show that proposed technique(the block-based time reversal technique using the vector sensor) is useful in the time varying shallow water.

II. Field Measurements

The underwater acoustic communication using vector sensor was conducted on May 24-25, 2017, in a shallow-water region off the island of Geoje located at 34° 43′ N, 128° 39′ E, south of Korea, where the water depth was 28 to 32 m [Fig. 1. (a)]. This location was characterized by silt sediment.

The omni-directional transducer (NEPTUNE D-11) was deployed at 13 m depth from ADD(Agency for Defense Development) research vessel(R/V Mirae). And, the communication signals were measured by vector sensor receiver (IVAR-2) of Applied Physics Lab, University. of Washington, USA, which was positioned roughly 1 m above the bottom [Fig. 1. (b)].

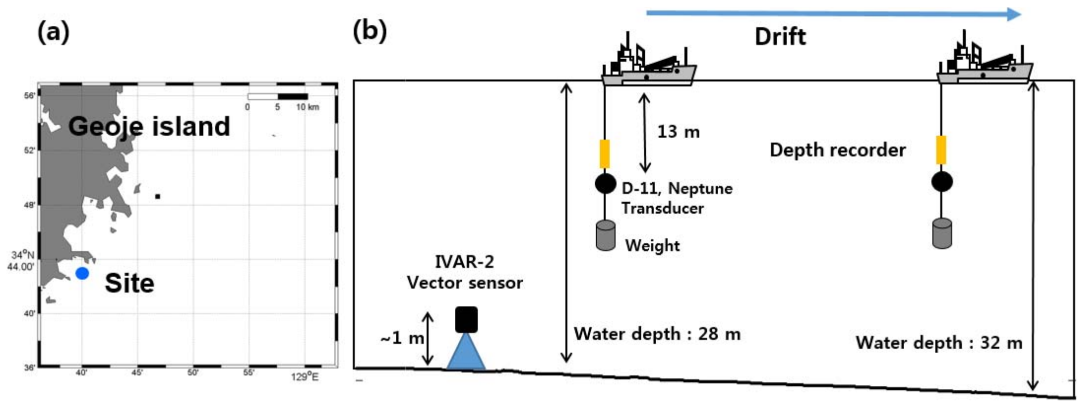

Fig. 1. (a) Site of communication experiments; (b) The experimental geometry

The communication sequence consisted of a 100-ms-long linear frequency-modulated (LFM) pulse with a bandwidth of 2.5–3.5 kHz as a probe signal, followed by a pause lasting 1 s, followed by quadrature phase shift keying (QPSK) sequences lasting 7.2 s with a center frequency of 3 kHz. The signal bandwidth was 1 kHz.

III. Results

The vector sensor signals are made up of pressure signal and x, y, z component of particle velocity signals. Figure 2 shows measured vector sensor signals for source-receiver range of 137 m [Fig. 2. (a)] and 453 m [Fig. 2. (b)].

Conventional time reversal technique assumes that the channel is time invariant. If the channel is varied rapidly with time, it is required to apply a block-based time reversal technique with channel updates using the precious symbols. Initial channel is estimated using a least square algorithm from the training symbols. Second, time reversed channels are convolved with the next block of symbols and combined to obtain the focused symbols. Third, time reversal combining is followed by a single phase locked loop (PLL) to compensate for the phase distortion in communication data and decision feedback equalizer (DFE) to eliminate the residual ISI. Lastly, estimated symbols are used for updating the channel estimates, which are then applied to the next block of symbols.

Figure 3 shows the communication performance estimated using the four different techniques for the source-receiver range 453 m. Figure 3 (a) and (b) are the scatterplots of communication performance obtained based on the time invariant channel. In a case, conventional time reversal using single pressure sensor, communication performance has low. BER(Bit Error Rate) is 7.1 % and output SNR(Signal to Noise Ratio) is 5.8 dB. However, in the case, conventional time reversal using vector sensor, communication performance improves. BER is 1.1 % and output SNR is 12.2 dB. Figure 3 (c) and (d) are the scatterplots of communication performance obtained based on the time varying channel. In the case, block-based time reversal using single pressure sensor, communication performance has similar to conventional time reversal using vector sensor technique. BER and output SNR are 1.2 % and 10.7 dB. However, the block-based time reversal using vector sensor achieve error-free communication performance and high output SNR(15.3 dB).

These results imply that proposed technique(the block-based time reversal technique using the vector sensor) is useful in the time varying shallow water.

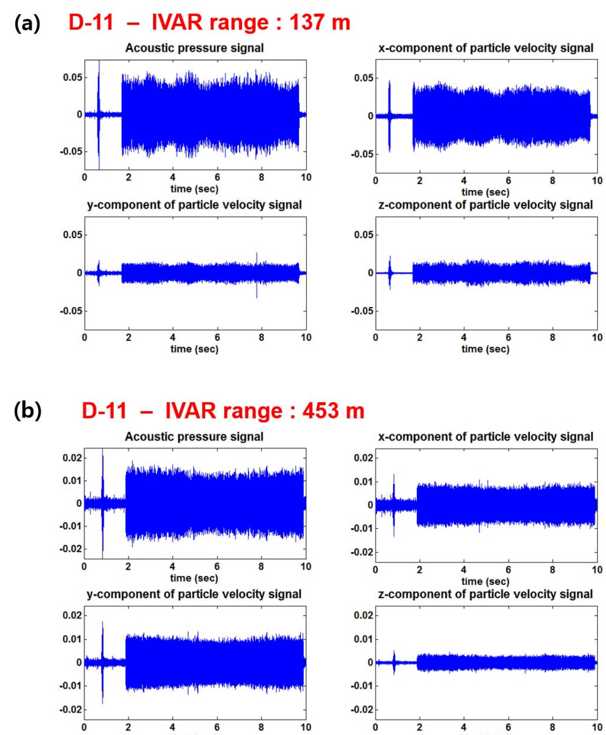

Fig. 2. Measured vector sensor signals for the source - receiver range of (a) 137 m, (b) 453 m.

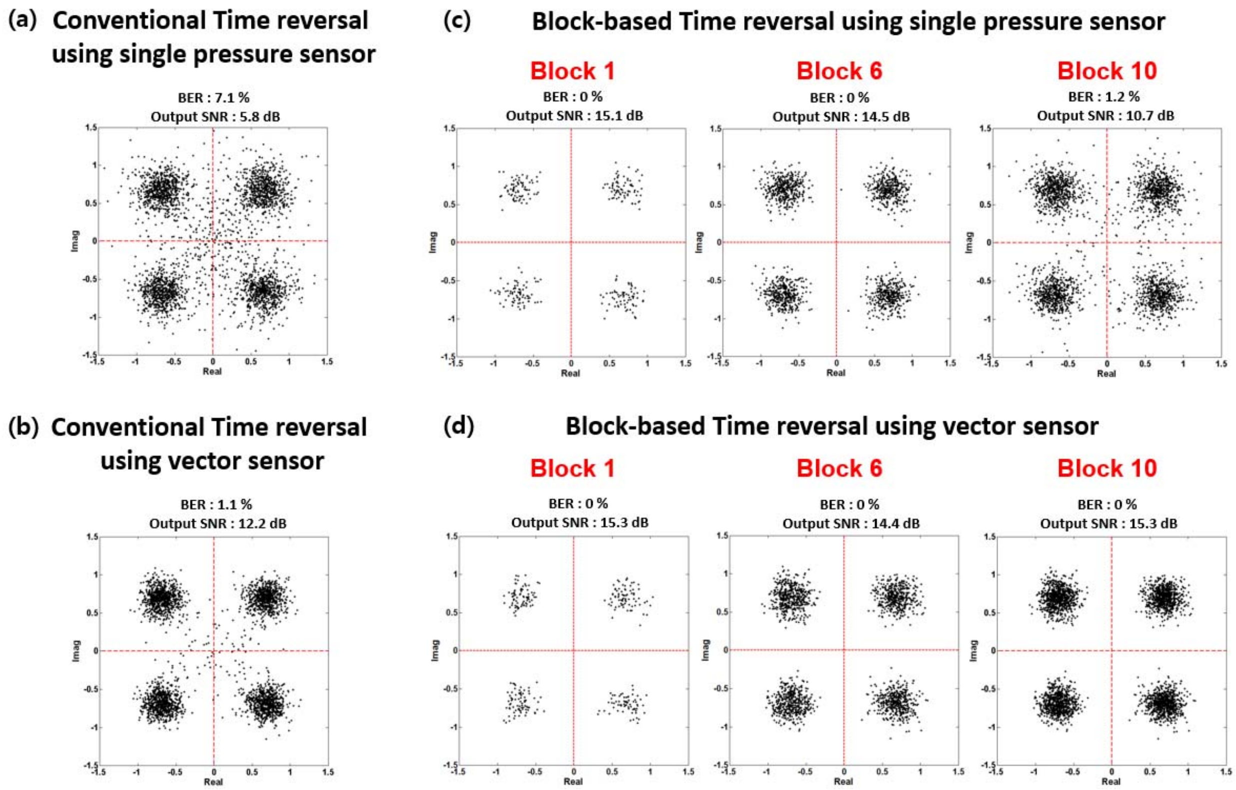

Fig. 3. the communication performance estimated using the four different techniques for the source-receiver range of 453 m. (a) conventional time reversal using single pressure sensor, (b) conventional time reversal using vector sensor, (c) block-based time reversal using single pressure sensor, (d) block-based time reversal using vector sensor.

IV. CONCLUSION

The time reversal process improves communication performance by reducing ISI and increasing the signal-to-noise ratio (SNR). However, this causes the deterioration of spatial efficiency. The vector sensor measures acoustic pressure signal as well as x, y, and z-components of the particle velocity at a single point, and these signals can be used as a single-input multiple-output system (SIMO) for underwater acoustic communication. In this study, an underwater communication experiment using a vector sensor in time varying shallow water. The communication results show that proposed technique(the block-based time reversal technique using the vector sensor) is useful in the time varying shallow water.

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REFERENCES

[1] T.C. Yang, "Properties of underwater acoustic communication channels in shallow water," J. Acoust. Soc. Am. 131, 129-145 (2012).

[2] D. Rouseff, M. Badiey, and A. Song, "Effect of reflected and refracted signals on coherent underwater acoustic communication: Results from the Kauai experiment (KauaiEx 2003)," J. Acoust. Soc. Am. 126, 2359-2366 (2009).

[3] A. Song, M. Badiey, H.C. Song, S. Hodgkiss and M.B. Porter, "Impact of ocean variability on coherent underwater acoustic communications during the Kauai experiment (KauaiEx)," J. Acoust. Soc. Am. 123, 856-865 (2008).

[4] P.A. Walree, "Propagation and Scattering Effects in Underwater Acoustic Communication Channels," IEEE J. Ocean. Eng. 38, 614-631 (2013).

[5] T.C. Yang, "Measurements of temporal coherence of sound transmissions through shallow water," J. Acoust. Soc. Am. 120, 2595-2614 (2006).

[6] G.F. Edelmann, H.C. Song, S. Kim, W.S. Hodgkiss, W.A. Kuperman and T. Akal, "Underwater Acoustic Communications Using Time Reversal." IEEE J. Ocean. Eng. 30, 852-864 (2005).

[7] H.C. Song, W.S. Hodgkiss, W.A. Kuperman, W.J. Higley, K. Raghukumar and T. Akal, "Spatial diversity in passive time reversal communications.

[8] F.J. Fahy, Sound Intensity, E&FN Spon, London, 1053-1075 (1995).