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Suppression of effects of synchronization error with Adaptive digital down-conversion on underwater acoustic communication

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1. Introduction

In underwater acoustic communication (UWAC), the Doppler shifts severely affect received signals and degrade demodulation performance. In particular, the uniform Doppler shift of a direct signal causes fast linear phase shifts and changes in an interval of received symbols. To reduce the effects, the replica frequency and down-sampled time has been conventionally adjusted at a digital down-conversion (DDC) step on demodulation. The adjustment is based on estimates of the uniform Doppler shifts yielded by measurement of the received signal length. Therefore, the DDC can effectively compensate for both the phase shifts and the temporal changes caused by the uniform Doppler shift as far as it is successfully estimated. On the other hand, wrong estimation of the uniform Doppler shift can happen in the real world because multipath signals and various noises can lead to inaccurate measurement of the received signal length. It causes wrong estimation of the uniform Doppler shift and degrade the demodulation performance.

Recently, an adaptive DDC (ADDC) has been recently proposed to suppress effects of temporal instabilities caused by the nonuniform component of the Doppler shift of the direct signal.[1)] In the previous study, simulation results have shown that the ADDC effectively work to suppress the degradation due to the temporal instabilities.

In this study, it is investigated that the ADDC can compensate for wrong estimation of an interval of received symbols caused by inaccurate measurement of received signal length based on acoustic data in an at-sea experiment.

2. Adaptive digital down-conversion

Let the propagation time of the direct signal for the kth receiver denoted by $\tau_{0,k}(t)$. Futhermore, $t_{0,k}^{\mathrm{rx}}$ represents the time when the beginning part of the direct signal is received at the kth receiver. Then, using the constant $\tau_{0,k}\left(t_{0,k}^{\mathrm{rx}}\right)$, linear term $\beta_k(t-t_{0,k}^{\mathrm{rx}})$, and nonlinear term $\tau_{0,k}^{\mathrm{nl}}(t)$, the time $\tau_{0,k}(t)$ can be expressed as

$$\tau_{0,k}(t) = \tau_{0,k}\left(t_{0,k}^{\mathrm{rx}}\right) + \beta_k\left(t-t_{0,k}^{\mathrm{rx}}\right) + \tau_{0,k}^{\mathrm{nl}}(t), \quad (1)$$

where β_k denotes the constant of proportionality.[1,2)] Both of convensitonal DDC and ADDC compensate for $\beta_k\left(t-t_{0,k}^{\mathrm{rx}}\right)$ based on the measurement of the received signal length. In additon, the ADDC can compensate for $\tau_{0,k}^{\mathrm{nl}}(t)$ (t) using the nonlinear phase shifts estimated by a decision feedback equalizer (DFE), which is a signal processing consisting of a digital phase lock loop (DPLL), and the feedforward and feedback filters. The block diagram of the ADDC combined with the DFE is depicted in **Fig. 1**.

If β_k is wrongly estimated, the inaccurate replica frequency at the DDC or ADDC causes a residual phase error which the DPLL in the DFE has to compensate for. Furthermore, in case of conventional DDC, the wrong estimation of β_k also causes errors of down sampled time. On the other hand, the ADDC can compensate for the down-sampled time error according to the estimated phase shift in the DFE. Therefore, the ADDC theoretically has an advantage in case of inaccurate estimation of the uniform Doppler shift of the direct signal.

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3. At-sea experiment

In this study, the ADDC was applied to data obtained in a previous at-sea experiment. In the experiment, a source was moored at a depth of 1720 m approximately, and receiver array composed of five elements was embedded at the bottom of the autonomous surface vehicle (ASV). The configuration is depicted in **Fig. 2**.

The ASV autonomously cluised along a planned circle with a thruster speed of 400 rpm, corresponding to 2 knot under static conditions. The test signals have the carrier frequency of 17 kHz and the bandwidth of 2 kHz and were transmitteed by the moored source. To measure the received signal length, synchronization siganls were located in beginning part and end of the signal. The transmitted signal length defined as the duration between synchronization signals was set to 3.28 s.

4. Results and discussion t

To investigate how the ADDC works under a condition of inaccurate measurement of the received signals length, a received signal was demodulated using the conventional DDC-DFE and ADDC-DFE in cases of correct and incorrect synchornization

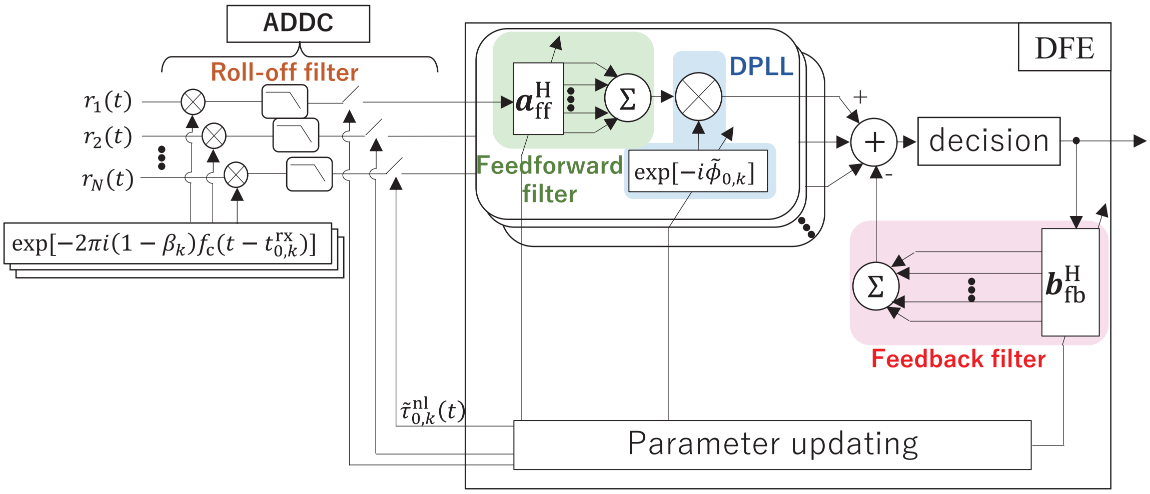

Fig. 2 Block diagram of ADDC-DFE.

points setting. In case of incorrect synchronization points, the received siganl length was measured 2.5 ms loger than that in case of correct measurement.

As demodulation results, constellations in cases of the DDC-DFE and ADDC-DFE under conditions of accurate and inaccurate measurement of the received signal length are shown in **Fig. 3**. Whereas the accurate measurement offered 0.48 knot as the uniform Doppler shift of the direc signal, the inaccurate measurement offered 2.70 knot.

In case of accurate measurement, output signal to noise ratios (SNRs) of the DDC-DFE and ADDC-DFE were equal to 17.14 dB and 18.01 dB, respectively. The difference comes from the ADDC working to compensate for the temporal changes caused by the nonuniform component of the Doppler shift of the direct signal. On the other hand, the output SNRs of the DDC-DFE and ADDC-DFE equal 9.23 dB and 16.64 dB in case of inaccurate measurement, respectively. The results means that the ADDC can improve demodulation perforamnce when the uniform Doppler shift of the direct signal is wrongly measured.

5. Summary

The conventional DDC compensates for effects of the uniform Doppler shift of the direct signal based on measuement of a signal length. Therefore, the inaccurate measurement degrades the demodulation performance. In this study, it was ivenstigated how the ADDC works in case of inaccurate measurement of the uniform Doppler shift of the direct signal. The results reveal that the ADDC compensates for the temporal changes caused by the inaccurate measurement and improves the demodulation performance.

Acknowledgment

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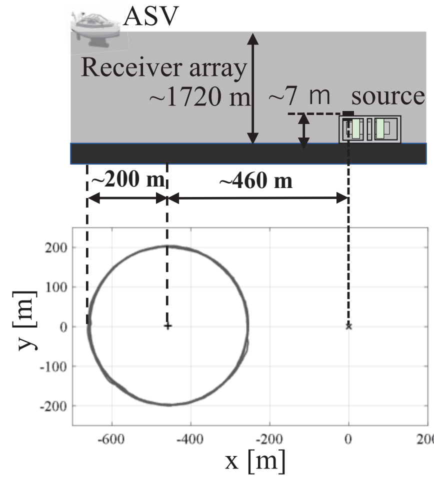

Fig. 1 Configuration of the experiment.

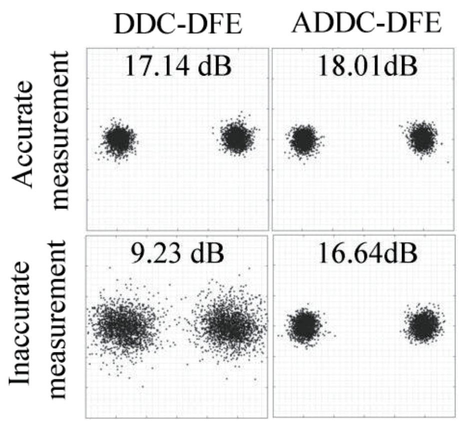

Fig. 3 Constellations of DDC-DFE (left panels) and ADDC-DFE (right panels) in cases of accurate and inaccurate measurement of the received signal length.

References

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