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Time-Delay based Mimicking Dolphin Whistle for Covert Underwater Communication

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1. Introduction

In underwater acoustic (UWA) communications, biomimetic communication methods have been researched for coverting transmission against enemies[1-3]. Chirp spread spectrum (CSS) was developed for mimicking dolphin whistle[3]. Since the CSS distorts the frequency contour of the actual dolphin whistle, the covertness of the CSS is small[3-4].

To increase the covertness, this paper proposes a time delay based modulation scheme keeping the actual whistle frequency contour. The proposed method does not utilize conventional digital communication symbols for transmission, but conveys binary information using time-delayed waveforms. If the transmission signals are the same as the dolphin whistle, the covertness of the proposed method becomes very large, and even the transmitted signals can not be distinguished from the actual dolphin whistle.

Using computer simulations, BER and mimicking performances of the proposed method were evaluated. Computer simulations showed that the proposed method had better BER and mimicking performances than the CSS.

2. Proposed method

The modulation and demodulation schemes of the proposed method are described in this section. Transmission information of the proposed method is allocated to the time-delay of dolphin signals.

For modulation, recorded dolphin signals cannot be directly utilized since the recorded dolphins are corrupted by background noise and interference. Firstly, new transmission signals with the same time-frequency characteristics as the dolphin whistle need to be generated. If the time-frequency characteristics of dolphin are known, the mimicked signal ($w(t)$) with the same time-frequency characteristics as the actual dolphin whistle can be generated as[4]

$$w(t) = \cos(2\pi f(t)t), \qquad (1)$$

where $f(t) = \int_0^t f_d(u)du$,
$f_d(u) = c_1 + c_2u^1 + \cdots c_{K-1}u^{K-2} + c_Ku^{K-1}$

Assume that the time-frequency characteristics of the whistle are extracted at every T interval and frequencies at all intervals are measured as f_T, f_{2T}, $\cdots$, $f_{(K-1)T}$, f_{KT}. Coefficient (c_k) in **Eq. 1** can be easily calculated because $f_d(kT) = f_{kT}c_k$ is satisfied for all k. Then, many $w(t)$ can be generated for different dolphin whistles.

The binary information is allocated to the time-delay of $w(t)$. If modulation order is M and m is an integer number of the integer set whose maximum value is M, the m-th time-delay can be mapped to binary information using Gray code. Then, the time-delayed signal ($s(t)$) is modulated as,

$$s(t) = \delta(t - m\tau) * w(t), \qquad (2)$$

where $*$ denotes convolution, and τ denotes τ_{max}/M, where τ_{max} denotes a maximum time delay of $s(t)$.

The actual dolphin whistle, the modulated signals of the CSS, and the proposed method are shown in **Fig. 1.** Since the proposed method utlizes the same signal waveforms as the actual whistle, the proposed method does not have any distortion of dolphin whistle, and exhibits better mimicking performance than the CSS.

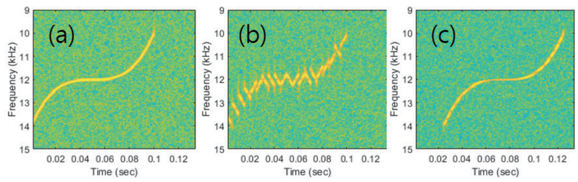

Fig. 1. Modulated signal, (a) Actual dolphin whistle; (b) CSS; (c) Proposed method.

The time-delay for every $w(t)$ varies and different $w(t)$ may be utilized for coverting transmission. Thus, the covertness of the proposed method becomes large and cannot be detected by a conventional cyclostationary detection, which detects unknown periodic symbol duration.

The demodulation of the proposed method is performed by estimating the time-delay through cross-correlation between the received signal ($r(t)$) and the trasnmitted $w(t)$. The every time delay ($\hat{\tau}$) of $w(t)$ is estimated by the following equation.

$$\hat{\tau} = \arg\max_{\alpha} |R_{rw}(\alpha)| \times f_s, \qquad (3)$$

$$\text{where } R_{rw}(\alpha) = \int_{-\infty}^{\infty} r(t)w^*(t-\alpha)dt$$

where f_s denotes a sampling frequency. The

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transmitted binary bits are demodulated by estimating m, which is calculated by $\hat{\tau}/\tau$.

In UWA channel environments, multipaths are caused by reflections from surfaces and bottoms. Since the multipaths also have the same information as the first arrival path, another time-delay can be measured by multipaths. To avoid this mis-detection, the time–delay of $w(t)$ needs to be carefully designed. If τ_{MED} is a maximum excess delay of dominant paths in UWA channel, modulation parameters (M and τ_{max}) satisfy the following equation to reduce the effects of the multipaths.

$$\tau_{MED} < \tau_{max}/2M. \qquad (4)$$

In the next section, BER and mimicking performances of the proposed method were evaluated alongside the conventional CSS using computer simulations.

3. Computer simulations

The BER performances were analyzed according to various modulation parameters, and the mimicking performances were analyzed through cross-correlation in time-frequency domain.

The modulation parameters of the proposed and the CSS methods were set as preserving the same data rates. **Table 1** shows the modulation parameters, data rates, and results of correlation coefficient. The UWA channel was generated using Bellhop based on a point of West sea of S. Korea and is shown in **Fig. 2**.

Table 1. Data rate and correlation coefficients

Scheme	CSS		Proposed method			
M	2		4		8	
L_t(msec)	50		-			
L_f(kHz)	0.5	1	-			
τ_{max}(msec)	-		32	64	32	64
Data rate(bps)	20		15	12	23	18
Correlation Coefficient	0.965	0.959	1			

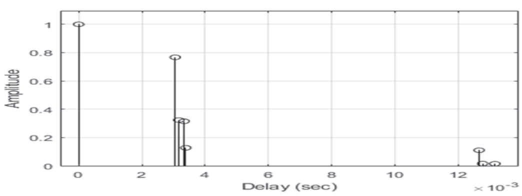

Fig. 2. Multipath channel delay profile.

For evaluating the degree of mimicking, correlations for two methods were measured and shown in **Table I**. The correlation coefficient of the proposed method presents one because dolphin whistles were used without a distortion. However, the correlation value of the CSS was less than one because the CSS divides a dolphin whistle with many up- or down-chirps.

Fig. 3 illustrates the BER performance of the CSS and the proposed method. The solid line denotes the BERs when τ_{max} of the proposed method is equal to 32 msec and the slot bandwidth of the CSS is 500 Hz. The dashed line denotes the BERs of 64 msec of τ_{max} for the proposed method and 1 kHz bandwidth of the CSS. If **Eq. 4** was not satisfied (i.e., blue-solid line with M=4), the BER of the proposed method was large. However, when **Eq. 4** was satisfied, the BER of the proposed method showed better than that of the CSS. In addition, the proposed method had about 3 dB better SNR gain than the CSS for the same BER.

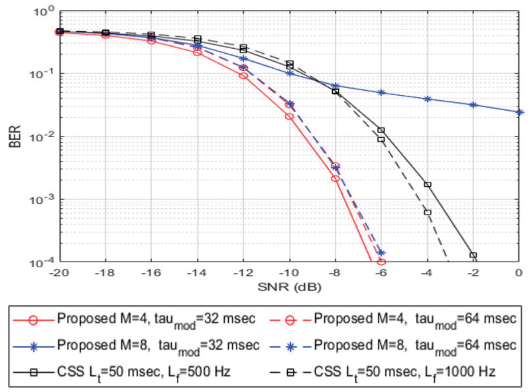

Fig. 3. BER performance.

As seen in **Table 1** and **Fig. 3**, the proposed method demonstrates better BER and mimicking performance than the CSS.

4. Conclusion

This paper proposes the time delay based covert communication scheme to improve the mimicking and BER performances. The computer simulations show that the BER and mimicking performances of the proposed method are better than that of the conventional CSS.

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