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A preliminary study on multiplexed signals by biomimetic pulse trains for underwater acoustic localization

Hanako Ogasawara[1†*], Takanobu Kuroyama[1], and Kazuyoshi Mori[1]
([1]National Defense Academy)

1. Introduction

The harbor security sonar system has been developed to safeguard critical facilities located within coastal areas. In the monitoring of coastal regions by surveillance vessels [1)], it is essential to detect intruders such as divers and autonomous underwater vehicles (AUVs) approaching from underwater. Recentrly, for the sake of automation and reduction in human involvement, AUVs have been progressively replacing manned surveillance.

Advancements have been made in the development of biomimetic AUVs that mimic the movement of fish movement using artificial muscles [2)]. Compared to conventional motor-driven AUVs, this type exhibits significantly low radiated noise. Consequently, it enables surveillance and tracking of targets without alerting them to its presence.

AUVs moving underwater engage in acoustic communication with transponders for position correction. Emitting artificial sounds during this process could potentially compromise the element of stealth by alerting the target. Thus, to maintain secrecy, we simulate the sounds of marine organisms indigenous to the area for acoustic communication with the transponder. This will enable inconspicuous position correction without arousing the target's awareness.

We propose a pulse sequence signal utilizing dolphin click sounds and demonstrate its efficacy in measuring accurate propagation times up to approximately 300 meters in environments with significant coastal multipath and ambient noise [3,4)]. Acoustic localization necessitates communication with at least three transponders concurrently. In this presentation, we calculate the cross-correlation properties of the proposed multiple pulse sequence signals and show the effectiveness of signal multiplexing using the proposed signals.

2. Signal generation method

Dolphins use pulse called as clicks for their communication, feeding and localization. They use the pulse train varying timing, intervals, range according to the application. It is known that they use different pulse train in their search phase, approach, and buzz phase. In search phase, they emitted at equal intervals and equal amplitudes. We use dolphin clicks signal which has multiple waves within a span of a few tens of microseconds [5)]. **Figure 1** shows the way of pulse train generation in search phase. Dolphins emit pulses at regular intervals, although these intervals are not precisely identical like those generated by machines. So, we assume some fluctuations both in amplitude A_w and inter-pulse-intervals T_w. In previous studies, we estimated the suitable interval fluctuations and amplitude fluctuations. It is confirmed that 101 pulse trains with 10 ms interval fluctuations is suitable for signal detection up to 300 m. So, in this study we generate

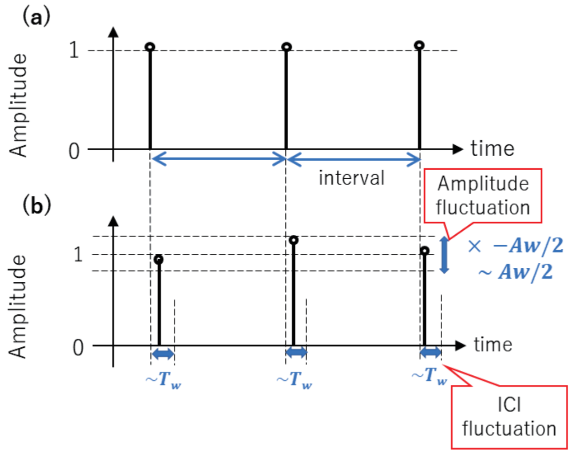

Fig. 1 A way to generate pulse trains. (a) pulse train with equal interval and equal amplitude, (b) pulse train with fluctuated inter-click intervals and the amplitudes of pulses.

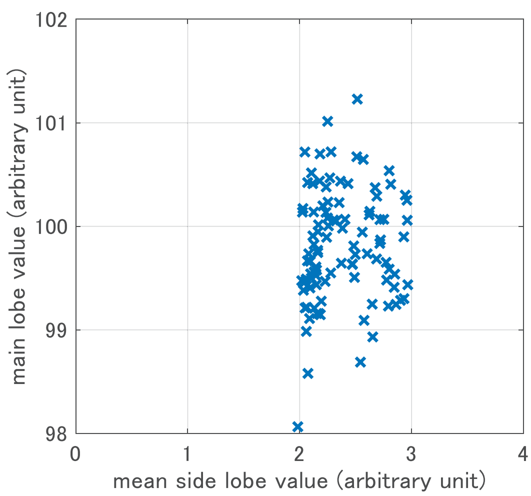

Fig. 2 Main lobe peak value and side lobe mean value of generated pulse trains.

E-mail: †*ogasawar@nda.ac.jp

101 pulse trains of 100ms intervals within 10 ms fluctuations and 0.1 times amplitude fluctuations. The fluctuation value varied each interval using random function. 100 types of pulse trains were generated using different fluctuations and calculated its auto-correlation function. To detect the signal in noisy conditions, it is important to get high main lobe and low side lobes in auto-correlation function. Figure.2 shows the relations of main lobe peak value and side lobe mean value in 100 different pulse trains. It is a normalized value based on the correlation peak of a single pulse as the reference. As the mean side lobe peak is 2.38 and its standard deviation is 0.3, the values of the pulse train's bottom side lobes are not large differences. As a result, we will select the three pulse trains with the largest main lobes for the evaluation of the multiplexed signal.

3. Cross-correlation of signals

The results of computing the cross-correlation functions for the three selected pulse trains selected in section 2 are presented in Fig. 3. All values are normalized by the peak value of the auto-correlation function of a single pulse. The diagonal displays the auto-correlation functions. As there are 101 pulse sequences, the peak values of the main lobes of all auto-correlation functions have increased to nearly 100 times compared to that of a single pulse. On the other hand, the values of the cross-correlation functions are uniformly low, indicating a low probability of erroneous detection even under multiplexed transmission.

4. Conclusion

We have proposed a pulse sequence mimicking dolphin clicks as the communication signal with transponders for acoustic localization. Through the cross-correlation functions of multiple pulse trains, it is observed that the inter-train correlation is low, ensuring that the signals can be simultaneously transmitted without interference. It implies the feasibility of signal multiplexing through these pulse trains.

Acknowledgment

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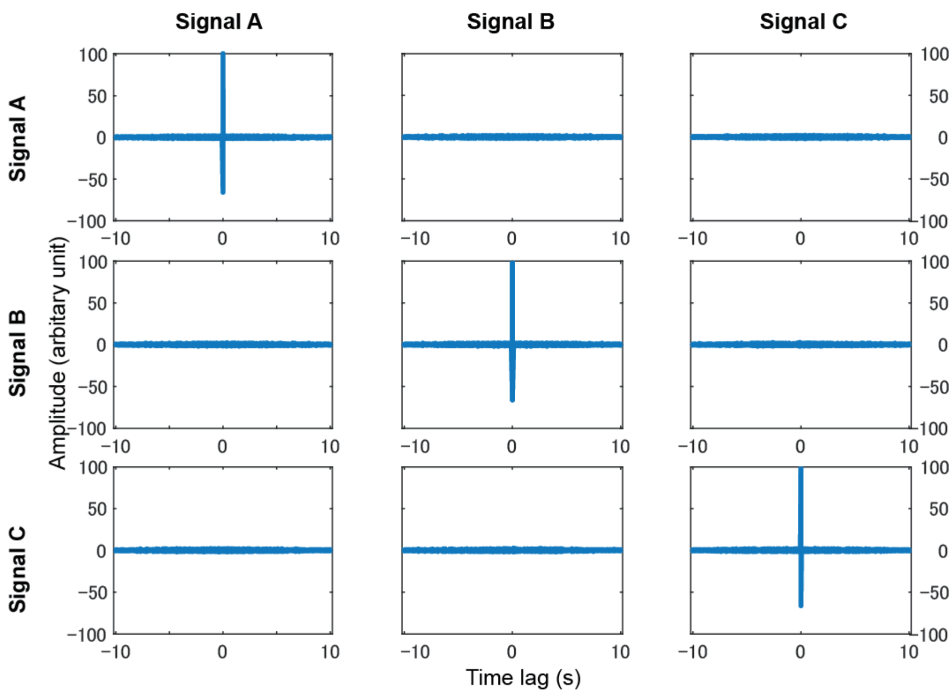

Fig. 3 auto-correlation functions and cross correlation functions of three different pulse trains.