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A Basic Study of Bio-mimic Pulse Train Generation for Underwater Acoustic Localization

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1. Introduction

Utilization of dolphin like bio-mimic signals are proposed for underwater acoustic localization assuming water-side security using an extreme low radiated noise underwater vehicle. We already investigated bottlenose dolphin clicks to apply to a site offshore Satsumasendai, Kagoshima using ray tracing method [1]. In this study, a method of pulse train generation imitating clicks sequence of dolphin feeding is proposed, and the detection performance of this pulse train is evaluated.

2. Proposed pulse train

Dolphins use echolocation, a sonar ability, to percept space and catch fish [2]. The sound waves used for echolocation are called clicks. The clicks sequence during feeding changes in three stages: i) search mode, in which the clicks pulses are emitted at equal intervals and equal amplitudes; ii) approach mode, in which the pulse intervals become shorter, and those amplitudes become smaller as they approach prey; and iii) terminal buzz, in which the pulses are continuously emitted at short intervals with small amplitudes just before feeding. We propose a method to generate a pulse train imitating the search mode clicks train. Here, the transmit timings and the amplitudes of pulses are fluctuated like a living dolphin. **Fig. 1** shows a way to generate pulse trains. The pulse train with equal interval of 100 ms and equal amplitude is shown in Fig. 1(a). The fluctuated pulse train is shown in Fig. 1(b). Each transmit timing is fluctuated within 1 ms from that of Fig. 1(a). Each amplitude is also fluctuated from 0.8 to 1.0 time relative to that of Fig. 1(b). The fluctuated values are generated by uniform random numbers.

Fig. 2 shows the waveforms [3] and autocorrelation functions of both single pulse of bottlenose dolphin clicks and fluctuated pulse train imitating search mode composed of 31 clicks. The peak-to-peak source sound pressure level of the bottlenose dolphin is 220 dB re 1 μPa at 1 m (peak-to-peak sound pressure of 1×10^5 Pa). Each autocorrelation function has one sharp peak. The peak value of the autocorrelation function the fluctuated pulse train is about 25 times higher than

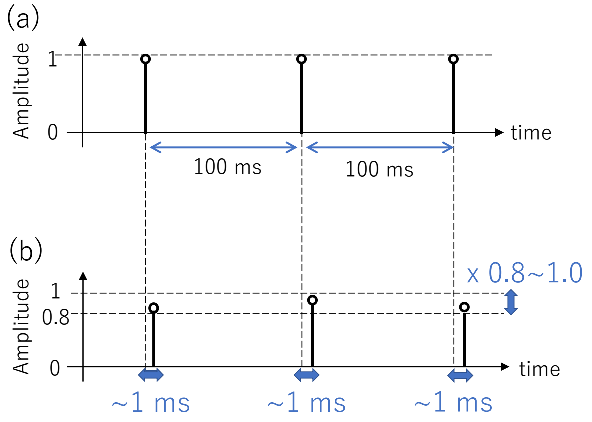

Fig. 1 A way to generate pulse trains. (a) pulse train with equal interval and equal amplitude, (b) fluctuated pulse train. The transmit timings and the amplitudes of pulses are fluctuated.

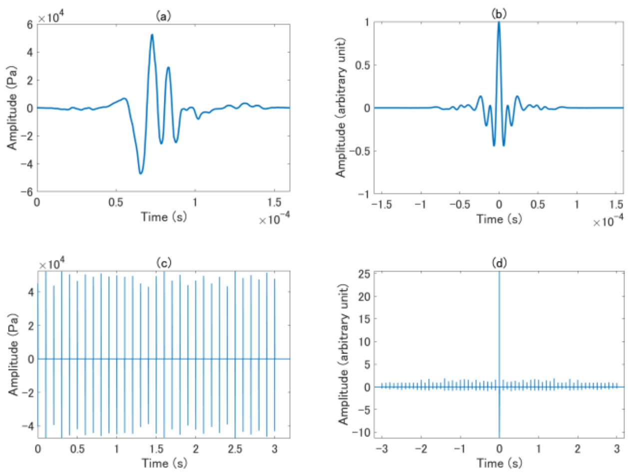

Fig. 2 Transmit waveforms. (a) single pulse of bottlenose dolphin clicks, (b) autocorrelation of (a), (c) fluctuated pulse train composed of 31 clicks (d) autocorrelation of (c).

that of a single pulse.

3. Evaluation of detection error

The analyses were conducted to simulate sound propagation assuming real coastal water conditions. Here, the sound ray analysis was performed offshore Satsumasendai, Kagoshima in winter, 2021 [1].

The received signal was computed by combining all arrival signals through all ray paths.

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Each arrival signal was calculated by affections of arrival time, spreading loss, absorption loss, sea surface reflection, and sea bottom reflection, respectively, corresponding to each eigen ray. And the received signal was synthesized with the coastal biological noise measured in Hashirimizu port of National Defense Academy. Here, the main noise source was snapping shrimp. The detection error evaluated here is difference between the arrival time of the direct wave and the peak time obtained from the cross-correlation function between the received signal and the transmitted signal.

The detection error was evaluated by varying the distance in the sound propagation simulation to 50, 100, 200, 300, 500, and 1000 m. The results using single pulse are shown in **Fig. 3**, and the results using fluctuated pulse train are shown in **Fig. 4**.

Fig. 3 shows that the signal-to-noise ratio (SNR) decreases as the distance increases, and the error increases accordingly. The numbers of errors are 3 at 50 m, 13 at 100 m, 32 at 200 m, 49 at 300 m, 96 at 500 m, and 100 at 1000 m, in every 100 trials, respectively.

Fig. 4 shows that the SNR having large error is smaller than that of Fig. 3, although the SNR decreases as the distance increases, as in the case of the single pulse, and the error increases accordingly. The errors at 50 m and 100m are free. The numbers of errors are 8 at 200 m, 15 at 300 m, 53 at 500 m, and 100 at 1000 m, in every 100 trials, respectively. Clearly, below the distance of 500 m, the number of errors of the fluctuated pulse train is fewer than that of the single pulse.

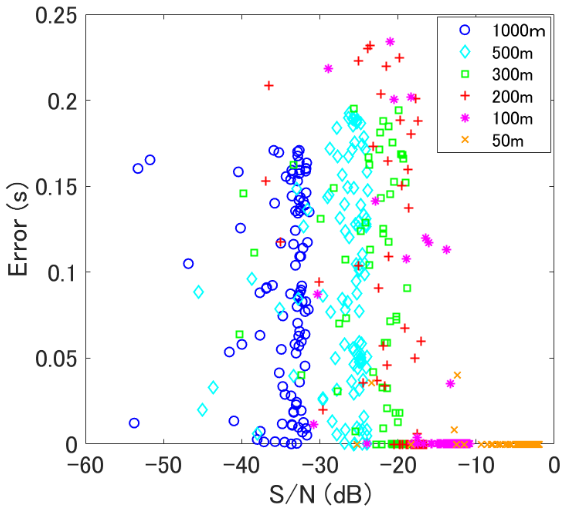

Fig. 3 Detection error vs. S/N ratio using single pulse

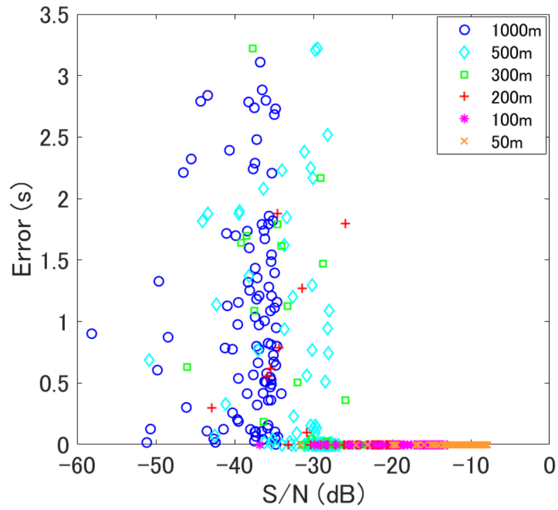

Fig. 4 Detection error vs. S/N ratio using fluctuated pulse train

4. Conclusion

In this study, a method of pulse train generation imitating clicks sequence of dolphin feeding was proposed, and the detection performance of this pulse train was evaluated.

We proposed a method to generate a pulse train imitating the search mode clicks train called fluctuated pulse train. Each transmit timing was fluctuated, and each amplitude was also fluctuated.

Here, the received signal was calculated by sound ray analysis using environmental data obtained off the coast of Satsumasendai, Kagoshima. The detection errors tended to increase with increasing distance and decreasing SNR. The fluctuated pulse train was more advantageous than the single pulse, with fewer number of errors.

In the future, we plan to further investigate methods of pulse train generation, including pulse trains of approach mode and terminal buzz, which may be effective against the coastal noise in this study.

Our idea will be avail to covert navigation for an extreme low radiated noise underwater vehicle in water-side security. It is expected that the proposed pulse train like dolphin clicks is effective to blend with the surround sounds in coastal water. Additionally, it may be also advantageous to detect the proposed pulse train against coastal noises.

Acknowledgment

The dolphin sound waveforms used in this study were taken from Dr. Tomohito Imaizumi's paper [3]. We would like to express our gratitude to Dr. Imaizumi.

References

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