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# Target detection using airborne ultrasound alternately modulated by different M-sequence codes for extension of measurable distance

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## 1. Introduction

An ultrasonic sensor is widely used to be applied in a distance measurement system. The pulse-echo method is one of the typical methods to measure the pulse-propagation distance by determining the time of flight (TOF). Nevertheless, the signal-to-noise ratio (SNR) of the received signal in short-pulse transmission to improve the distance resolution is degraded by the effect on environmental noise. Pulse compression has been introduced to the pulse-echo method for improvment of the SNR and the resolution. An M-sequence is one of the binary pseudo random codes, which is generated from a linear feedback shift resister (LFSR). The M-sequence is used to modulate the transmitted ultrasound in pulse compression. Then, the received signal is correlated with the transmitted signal. Sharp peaks occur when the code in ultrasound match the transmitted code. Therefore, the TOF of ultrasound can be determined by the peak in the cross-correlation function. The peak interval corresponds the maximin measurable distance and the temporal resolution of measurement. In the case of a long M-sequence, the long measurable distance can be achieved, however, the temporal resolution is degraded.

In this research, the alternate transmission of two different M-sequence codes is used to extend the measurable distance without degradation of the temporal resolution. Then, the received signal is correlated with each M-sequence code. Sharp peaks to determine TOFs alternately occur in each cross-correlation function. Therefore, the measurable distance can double and the temporal resolution is same as the single transmission of each code.

## 2. Method

In this report, to demonstrate the extension of measurable distance by the proposed method, distance measurement using airborne ultrasound was proceeded. In the experiment, the suitable combination of 9th-order M-sequence codes (codes A and B), in which there is the lowest interference[1], was used to modulate ultrasound. The number of characters in the single 9th-order M-sequence code is 511 digits. The 6 cycles of code A and 3 sequences of codes A and B were used as the original and proposed methods, respectively. These signals were generated from the function generator and transmitted from the loudspeaker, as illustrated in **Fig. 1**. Then, the reflected echoes from the target were received by the microphone. The carrier frequency of the transmitted signal was 25 kHz. The cut-off frequency of the HPF and the sampling frequency of the oscilloscope were 1 kHz and 4 MHz.

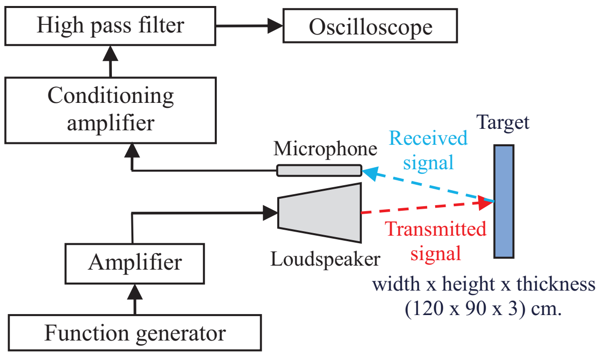


Fig. 1 Setup of measurement system.

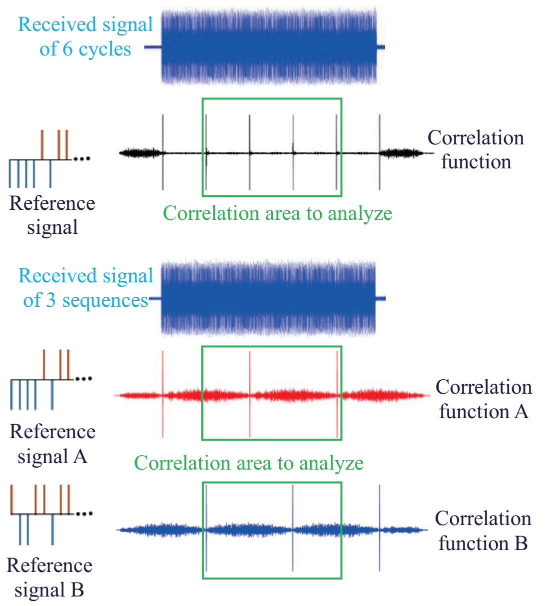


Fig. 2 Cross-correlation methods of the single transmission (original) and alternate transmission (proposed) in M-sequence pulse compression.

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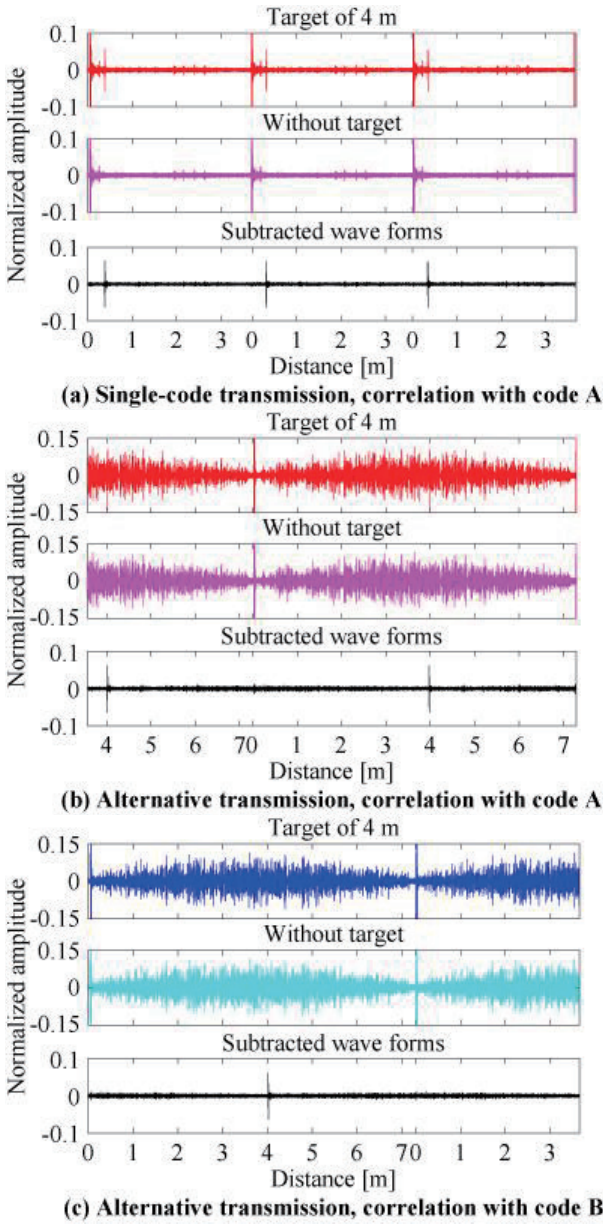


Fig. 3 Cross-correlation functions of the original (a) and proposed methods (b) and (c) in cases the target distance is 4 m.

In the original method, there are 6 peaks in the cross-correlation function. Distances within 3.66 m can be measured by 6 times, as illustrated in **Fig. 2**. In the proposed method, there are 3 peaks in each cross-correlation function with code A and B. Distances within 7.32 m can be measured by 3 times, respectively. By alternatively employing measured distances in the proposed method, the temporal resolution can be kept the same as the original method.

## 3. Results

Experimental results, cross-correlation functions, are illustrated in **Fig. 3**. Maximum amplitude of each cross-correlation function is normalized to 1. There are 3 cross-correlation functions in each correlation. Upper functions were achieved when the distance to the target was 4 m. Peaks around 0 m indicate directly waves. In Fig. 3 (b) and (c), there are large fluctuated signals between peaks. Those signals are interference noise of codes A and B in directly waves. Then, middle functions were achieved without the target. Effects by directly waves can be eliminated by subtraction of middle functions from upper functions, as bottom functions. The measurable distance of the original method is 3.66 m, therefore peaks by the echo signal from the target indicate approximately 0.3 m as the bottom function in Fig. 3 (a). On the other hand, peaks of the proposed method indicate approximately 4 m in Fig. 3 (b) and (c). Thus, the measurable distance of the proposed method could double. Furthermore, the temporal resolution can remain by using of Fig. 3 (b) and (c) alternatively for distance measurement.

Table I Maximum amplitudes of interference noises normalized by each target peak in the numerical calculation and the experiment.

| Method | Correlation with code A | Correlation with code B |
|---|---|---|
| Calculation | 0.0881 | 0.0920 |
| Experiment | 0.1156 | 0.1144 |

There are also interference noises of echo signals in bottom functions in Fig. 3 (b) and (c). Maximum amplitudes of interference noises in Fig. 3 (b) and (c) and those calculated by binary codes of A and B are shown in **Table I**. In the experiment, interference noises seem to be increased by overlapping of the impulse response of the loudspeaker.

## 4. Conclusion

The alternate transmission of different M-sequence codes has been proposed to extend the measurable distance of M-sequence pulse compression. In this report, distance measurement using airborne ultrasound with the proposed method was demonstrated. In the case of 9th-order M-sequence and the transmitted frequency of 25 kHz, the measurable distance is 3.66 m. However, the target distance of 4 m could be measured by the proposed method with the same temporal resolution of the original method.

## References

1. K. Leetang, S. Hirata, H. Hachiya: Jpn. J. Appl. Phys. **58** (2019) 076503.