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# Study about extension of measurable depth in M-sequence pulse compression by alternate transmission of different codes

異なる M 系列符号の交互送信による計測範囲の拡張に関する検討

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## 1. Introduction

In the ultrasonic pulse echo method, the distance or displacement of an object is measured from the time of flight (TOF) of an ultrasonic pulse (a reflected echo). The distance resolution depends on the pulse width. In the case of a short pulse, however, the signal-to-noise ratio (SNR) of the echo decreases. The time resolution (the time required for a single measurement) depends on the pulse-repetition time. There is a trade-off between the time resolution and the measurable depth. Pulse compression using an M-sequence is employed to the pulse echo method for improvement of the echo's SNR [1]. In M-sequence pulse compression, the length of an M-sequence code corresponds the pulse-repetition time. Moreover, the SNR increment is determined by the length. In this report, a method for extension of the measurable depth in M-sequence pulse compression by alternate transmission of different codes is described.

## 2. M-sequence pulse compression

An M-sequence is a pseudo-random binary code generated from a linear feedback shift register (LFSR). The $n$th-order M-sequence is generated from the $n$-bit LFSR, and the length of the M-sequence code $N$ is $2^n$-1. The amplitude or phase of ultrasound is modulated by the M-sequence code. The modulated signal is continuously or several cyclically transmitted in pulse compression. Then, the received signal is correlated with the reference signal corresponding to the transmitted signal. When codes in the received signal and the reference signal match, the high correlation value is obtained as illustrated in **Fig. 1**. Furthermore, the SNR increases by the square root of $N$ times.

## 3. Alternate transmission of different M-sequence codes

In M-sequence pulse compression, the measurable depth can be extended by increase of the M-sequence order. In that case, however, the time resolution is degraded. When the number or position of feedback taps in the LFSR change, the different M-sequence is generated. Correlation values between different codes are lower than the correlation peak.

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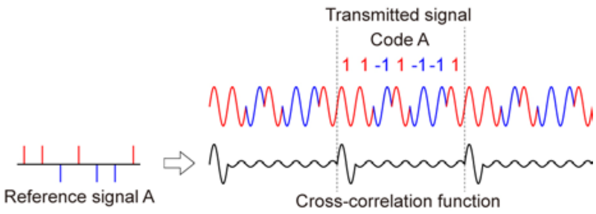


Fig. 1 Cross-correlation function between 3rd-order M-sequence-modulated signal and reference signal.

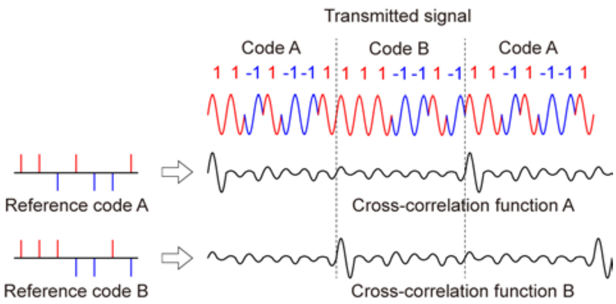


Fig. 2 Cross-correlation functions in the case of alternate transmission of two different M-sequence codes.

Therefore, different codes A and B are alternately transmitted in the proposed method as illustrated in **Fig. 2** [2]. Then, correlation peaks in the cross-correlation function A by the reference signal A and those in the cross-correlation function B by the reference signal B alternately arise. Therefore, the measurable depth doubles to keep the equal time resolution.

## 4. Evaluation of proposed method

In the proposed method, there are truncation noise and truncated interference noise around correlation peaks as illustrated in **Fig. 3**. The SNR of the peak is degraded by these noises. Truncation noise and truncated interference noise varies depending on the initial value in each M-sequence or the combination of M-sequences [3]. Therefore, the maximum peak of absolute noise (MP) and the standard deviation of noise (STD) are evaluated in all patterns of truncation noise and truncated interference noise.

In this report, the result of the 7th-order M-sequence is indicated as an example. In the

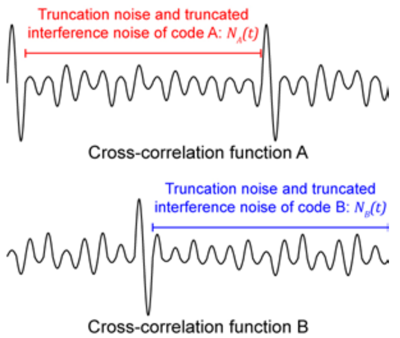


Fig. 3 Truncation noise and truncated interference noise in cross-correlation functions of 4th-order M-sequence.

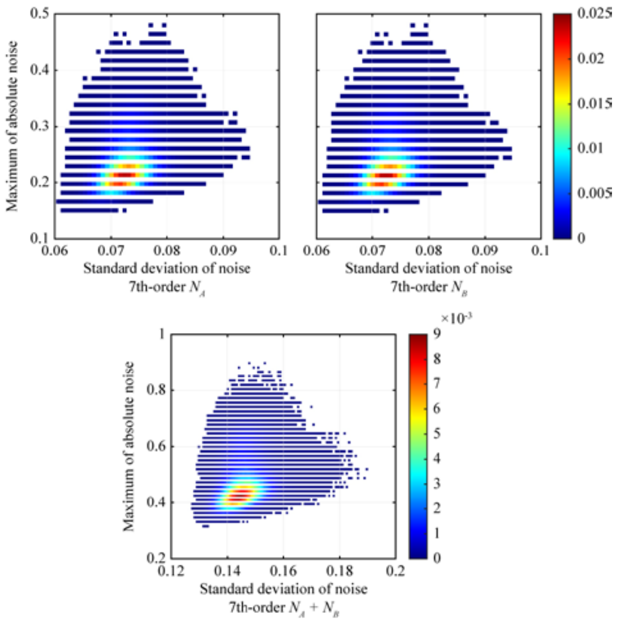


Fig. 4 2D histogram of MPs and STDs in $N_A$ and $N_B$ in the case of 7th-order M-sequence.

Table 1 Maximum-minimum values of MPs and STDs in $N_A$ and $N_B$ in the case of 7th-order M-sequence.

| | MP min-max | STD min-max |
|---|---|---|
| $N_A$ | 0.150 - 0.480 | 0.0608 - 0.0948 |
| $N_B$ | 0.150 - 0.480 | 0.0608 - 0.0948 |
| $N_A$+$N_B$ | 0.315 - 0.898 | 0.128 - 0.190 |

7th-order M-sequence, the kind of M-sequences is 18, and the combination of M-sequences is 153 patterns. In each M-sequence, the kind of initial values is 127. Therefore, there are 2467737 patterns of truncation noise and truncated interference noise. 2D histogram of MPs and STDs in $N_A$ and $N_B$ are shown in **Fig. 4**. In addition, maximum-minimum values of MPs and STDs are indicated in **Table 1**. In the proposed method, degradation of the SNR can be reduced by the selection of the initial value in each M-sequence or the combination of M-sequences. In case the pattern, whose MP in $N_A$+$N_B$ is minimum and STD in $N_A$+$N_B$ is small as possible, is defined as optimal, M-

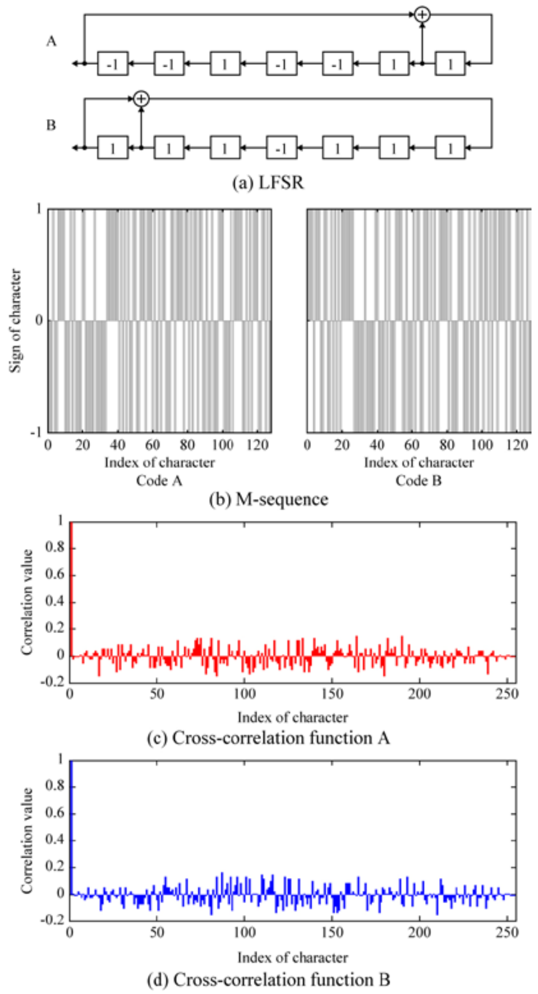


Fig. 5 Optimal M-sequence codes and cross-correlation functions in the case of 7th-order M-sequence.

sequences and their cross-correlation functions are shown in **Fig. 5**.

## 5. Conclusions

In M-sequence pulse compression, a method for extension of the measurable depth by alternate transmission of different codes is proposed. In the proposed method, The SNR of the correlation peaks is degraded by truncation noise and truncated interference noise. However, degradation of the SNR can be reduced by the selection of the initial value in each M-sequence or the combination of M-sequences.

## References

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