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Evaluation of SNR for alternate transmission of different coded ultrasounds to extend the limit of measurable distance in the pulse-echo method

Khanistha Leetang[1†], Shinnosuke Hirata[2], and Hiroyuki Hachiya[3] ([1,3]Grad. School Eng., Tokyo Tech; [2]Chiba Univ.)

1. Introduction

The pulse-echo method is a typical method for ultrasonic distance measurement based on pulse transmission and time-of-flight (TOF) determination. Moreover, in case of improving the signal-to-noise ratio (SNR), pulse compression is often employed for the pulse-echo method. In pulse compression, a frequency-swept signal or a pseudo-random modulated signal is transmitted, then, the received signal is correlated with the reference, which is the transmitted signal. When the received signal and the reference signal match, the high correlation value or compressed pulse appears in the cross-correlation function. The temporal resolution of the distance measurement is the time required for a single measurement. The short pulse-repetition time in the pulse-echo method represents the high temporal resolution. In that case, however, the long-distance cannot be measured because the pulse-repetition time corresponds to the maximum limit of the measurable TOF. Therefore, there is a trade-off relationship between the temporal resolution and the measurable distance in the pulse-echo method. To extend the measurable distance with degraded the temporal resolution, we have already proposed the alternate transmission of different signals[1,2]. In the previous method, the alternate transmission of M-sequence is studied to extend the measurable distance many times. However, noise between the sharp correlation peak occurs.

In this research, the alternate transmission of different LFM signals is studied for extending the limit of measurable distance in double times. Nevertheless, the noise amplitude of the alternate LFM signal is lower than the previous method. Moreover, the different noise characteristics among alternate LFM and M-sequence signal is indicated.

2. Method

In the proposed method, two different coded signals are alternatively and continually transmitted, then, the received signal is correlated with each reference signal to obtain each cross-correlation function as indicated in **Fig.1**. In each cross-correlation function, the compressed pulses alternatively occur, and the interval that

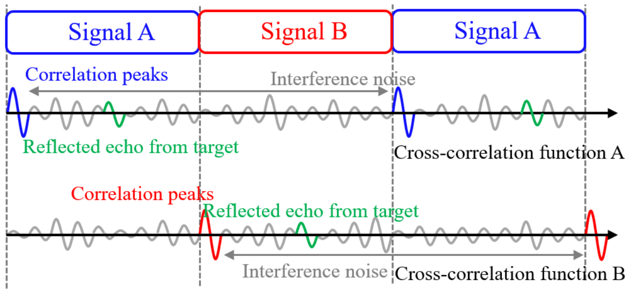


Fig. 1 Alternate transmission of different coded ultrasound in the pulse-echo method

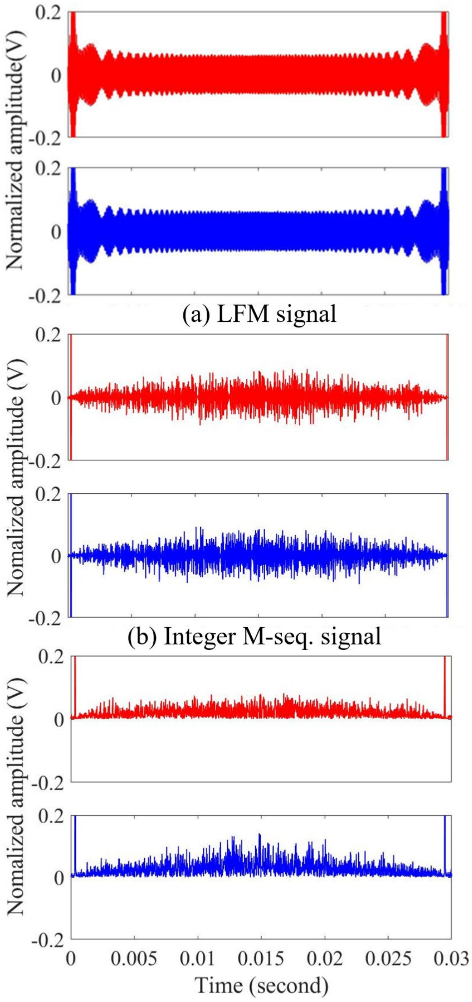
corresponds to the pulse-repetition time is extended by double of that in the one-code transmission. Therefore, the measurable distance can be extended with the same temporal resolution as the one-code transmission by the alternate distance measurement from each cross-correlation function. However, the noise by interference between different coded signals occurs between the compressed pulses. If the noise, which is defined as the noise between peaks (NBP), is larger than the compressed pulses, actual distance cannot be measured, and the SNR can be degraded. Therefore, the combination of different coded signals with low NBP is searched and the suitable combinations are determined.

3. Simulation

In the LFM signal, the combination of the up-chirp and the down-chirp can be employed to the alternate transmission. NBPs were estimated on the parameters, the center frequency of 35 kHz, the sweep bands from 10 kHz to 30 kHz, the signal lengths from 14.6 to 43.8 ms. Noise amplitude of high bandwidth and long length is decreased.

In the M-sequence, a few sine waves or their inverse waves are assigned to 1 or -1 for integer M-sequence. The modulation in which the initial phase of sine waves is conjugately shifted by 1 or -1 is also proposed, which is called complex M-sequence. Initial phases of different coded signals are shifted. In the cross-correlation function, the alternate transmission of phase-shifted complex M-sequence can be applied to suppress NBP. Therefore, the initial phase of different coded signals is shifted in the complex modulation. The variations of maximum of truncation and truncated interference noises, acquired from the phase

leetang@us.sc.e.titech.ac.jp, shin@chiba-u.jp, hachiya@sc.e.titech.ac.jp



(a) LFM signal

(b) Integer M-seq. signal

(c) Complex M-seq. signal

Fig. 2 Noise characteristic comparison of alternate transmission in the LFM (a), integer M-seq. (b) and complex M-seq. (c)

differences, are evaluated. Noise amplitude of NBP in the high order M-sequence is decreased. In the cross-correlation, noise characteristic among LFM and M-sequence signal is indicated in **Fig. 2**.

In the simulation, one cycle of one digit in the M-sequence signal is modulated. The maximum noise amplitude of NBP in the LFM signal and 35 kHz of M-sequence signal is indicated in **Table 1**. In case of the LFM signal, the maximum amplitude of NBP is decreased at long length of signal. However, the maximum amplitude of NBP in the M-sequence signal is decreased in the high order M-sequences. Therefore, the lowest NBP is selected from the proposed modulation in the M-sequence. However, if we modulated three cycles of one digit of 35 kHz in the 9th order M-sequence signal to transmit signal for reducing the overlapping impulse response of the speaker, the signal length is extended from 14.6 ms to 43.8 ms. In the alternate transmission method, different length of signal is only an effect with NBP of LFM signal. The maximum noise amplitude of NBP in the LFM

Table 1 Maximum noise amplitude comparison between LFM and 35 kHz of M-sequence signals from the simulations

Signal lengths (Order of M-seq.)	LFM signals	M-seq. signals	
		Integer M-seq.	Complex M-seq.
3.6 ms (7th order)	0.316	0.315	0.280
7.3 ms (8th order)	0.222	0.243	0.211
14.6 ms (9th order)	0.159	0.180	0.157
43.8 ms (9th order)	0.092	0.180	0.157

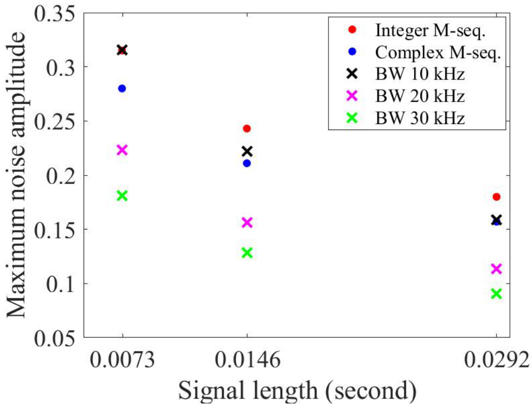


Fig. 3 Maximum noise amplitude comparison between LFM signal and M-sequence signal in the proposed method

signal is decreased when the LFM length is increased. In the high bandwidth, the maximum noise amplitude of NBP is decreased as indicated in **Fig. 3**. 10 kHz of relative bandwidth is general performance of the speaker. If we high performance of the speaker should be applied alternate LFM signal to extend the measurable distance in double times. However, high order M-sequence is decreased maximum NBP. Moreover, alternate M-sequence can extend the measurable distance many times.

4. Conclusion

Alternate transmission of different signals is applied to extend the measurable distance with degraded temporal resolution. If we have high performance to generate high bandwidth, the alternate transmission of different codes in the LFM signal for pulse compression should be applied in the proposed method. However, the number of codes for alternate transmission of LFM is only two different codes and distance expansion cannot be increased. On the other hand, the alternate transmission of M-sequence is many code combinations. It is easy to extend to measurable distance and design the signals.

References

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