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Coded signal pair for simultaneous ultrasound transmission in high-speed acoustic imaging
超音波同時送波による高速画像描画のためのコード化信号

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1. Introduction

Acoustic sensing in the air has the potential to acquire information about an object such as its position shape, material and movement effectively. We have been studying high-speed imaging technique by simultaneous transmission using coded signal for acoustic imaging in an indoor environment. Simultaneous transmission using two or more M-sequence signals enables high-speed imaging, but image degradation by an inter-code interference becomes the problem. In this paper, we investigated cross-correlation characteristics of all M-sequence pairs, and present a technique to remove the inter-code interference.

2. Acoustic imaging using M-sequence pair

2.1 Measurement system

For indoor acoustic imaging, we set up transmitter and receiver array and target, as shown in **Fig. 1**. Receiver array was set up in line between transmitter A and B.

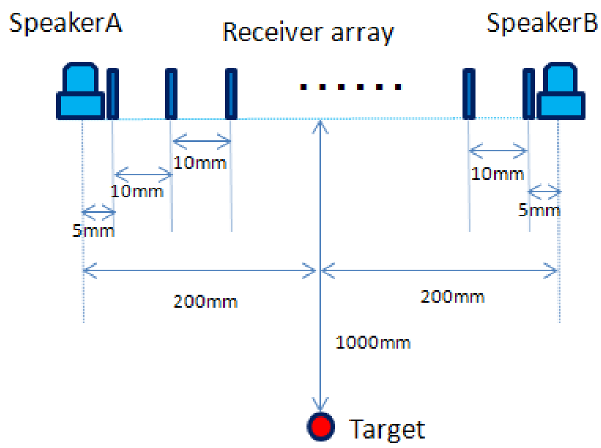
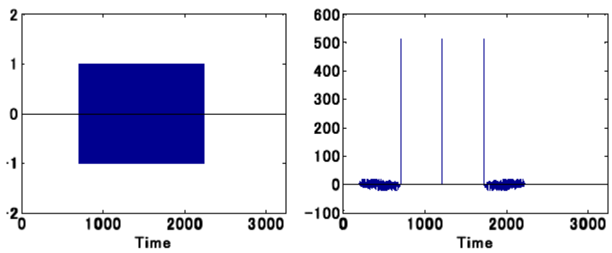


Fig. 1 Measurement system.

2.2 M-sequence

In this paper, we used M-sequence signal as transmission wave. M-sequence is one of PN-sequences, and it is composed of 0 and 1. We transmitted modulated M-sequence of 9 degree, as shown in **Fig. 2(a)**. After cross-correlation between received signal and replica, as shown in **Fig. 2(b)**, we are able to improve SN ratio. Transmitted wave has three cycles of M-sequence signal, so correlated signal has three peaks, but there is truncation noise at prior to first peak and posterior after the last peak. To remove truncation noise, we used the result of central peak of correlated signal. Value of 1 of M-sequence was assigned to sine wave of 25 kHz, and 0 was assigned to opposite phase of sine wave.



(a) M-sequence. (b) Autocorrelation.
Fig. 2 Correlation processing of received signal.

2.3 Preferred Pair

Preferred pair is a M-sequence pair having low cross-correlation value, and cross-correlation of preferred pair, as shown in **Fig. 3**, is called an inter-code interference. Enlarged illustration of the inter-code interference is shown in **Fig. 4(a)**, and histogram of the cross-correlation value of the inter-code interference is shown in **Fig.4(b)**.

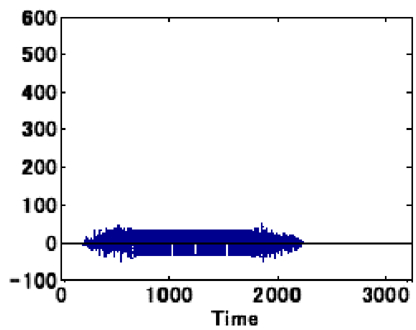
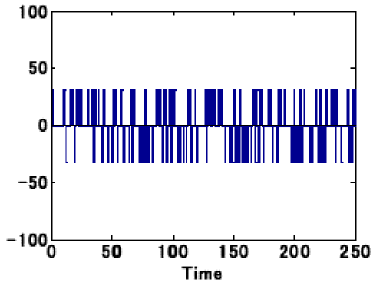


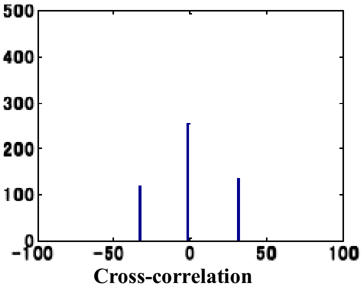
Fig. 3 Cross-correlation of Preferred Pair.

2.4 Acoustic imaging using Preferred Pair

Code A and code B M-sequence, which are preferred pair, were simultaneously transmitted from transmitter A and B. And we made cross-correlation between each received signal and code A or B, so we were able to separate the signals, and able to produce acoustic imaging. The result of imaging is shown in **Fig. 5**, and there is the inter-code interference in addition to the target.



(a) **Cross-correlation of Preferred Pair.**



(b) **Histogram of cross-correlation.**

Fig . 4 Cross-correlation of Preferred Pair.

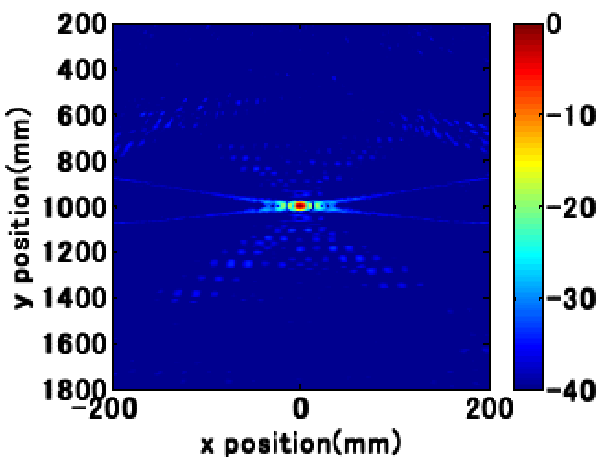
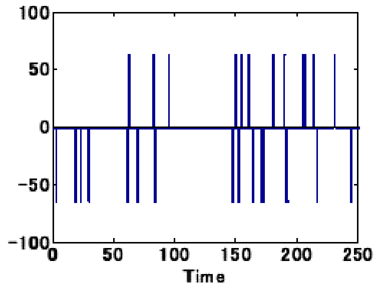
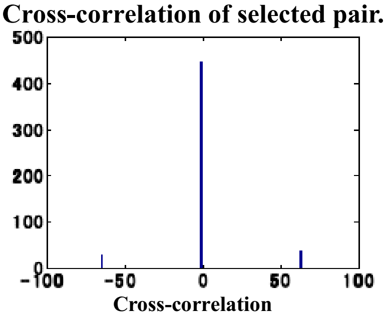


Fig . 5 Acoustic imaging using Preferred Pair.



(a) **Cross-correlation of selected pair.**



(b) **Histogram of cross-correlation.**

Fig . 6 Cross-correlation of Selected pair.

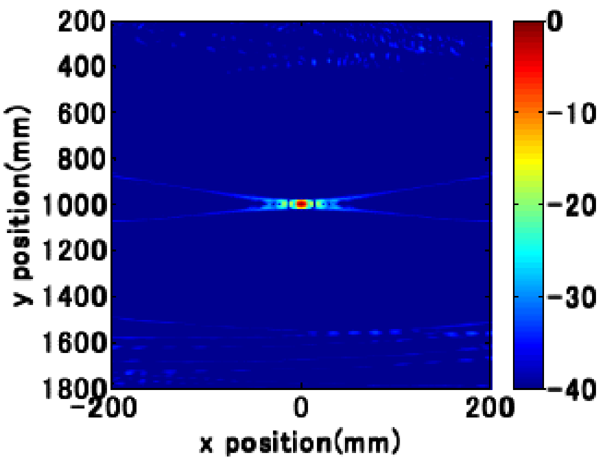


Fig . 7 Acoustic imaging using Selected Pair.

3 M-sequence pair proper for acoustic imaging

3.1 Selecting codes

There are 48 codes of M-sequence of 9 degree, so there are 1128 pairs of M-sequence codes. We investigated cross-correlation characteristics of all M-sequence pairs to remove the image degradation, and we found out proper M-sequence pair. Cross-correlation of this selected pair is shown in **Fig. 6**. Max cross-correlation value of selected pair is larger than max cross-correlation value of preferred pair, but the cross-correlation of selected pair has long sequence of small cross-correlation value that is -1. The cross-correlation of preferred pair has 14 sequence of -1, and the cross-correlation of selected pair has 52 sequence of a value of -1. By changing initial value of 9 digits of M-sequence, we can control the position of 52 sequence of -1 around the peak in cross-correlation. So we were able to remove the inter-code interference around the target.

3.2 Acoustic imaging using selected pair

Using selected M-sequence pair as transmission wave, result of imaging is shown in **Fig. 7**. We were able to remove the image degradation around the target.

4.Conclusion

By using selected M-sequence pair, we were able to perform the high-speed and high-resolution acoustic imaging. Image quality using proposed method is better than the image using preferred pair that is used conventionally.

References

1. Yong Wang et al.:Jpn. J. Appl. Phys., 47(5), 4319, 2008.
2. Hiroshi Matsuo et al.: Jpn. J. Appl. Phys., 47(5),4325, 2008.