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Sensitivity Compensated Transmitting Signal for Direction Measurement Using Pulse Compression
感度補正型送信信号によるパルス圧縮法を用いた方位計測法

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1. Introduction

Ultrasonic sensors are widely used for remote sensing in air such as automobiles and robots. For target ranging, pulse-echo method using pulse compression is usually employed. As a transmitting signal, frequency modulated (FM) signal is usually employed for high resolution measurement. However, owing to the sensitivities of ultrasonic transducers, a spectrum of received pulse echo signal will be uneven and narrow banded, and thus the effectiveness of pulse comression is lessened.

In order to acquire the the received signal with broader and flatter spectrum, a sensitivity compensated amplitude-modulated (SCAM) signal is proposed.[2] The SCAM signal is calculated from a linear FM signal (chirp wave) and a inversed filtering of the measured signal which mainly influenced by the sensitivities of ultrasonic transducers. Using the SCAM signal as the transmitting signal, the received signal will have a broader and flatter spectrum.

Here, by using the chirp wave for SCAM signal calculation, the SCAM signal becomes amplitude-modulated chirp wave. Therefore, it is expected that the signal to nose ratio (SNR) of the receved signal will be lower. In oder to acquire the receive signal with higher SNR and broader spectrum, a sensitivity compensated frequency-modulated (SCFM) signal is proposed.[3]

We have studied efficiency of pulse compression technique using these two type sensitivity compensated transmitting (SCT) signals for 1-D target ranging.[4] In this paper, 2-D direction measurement using pulse compression and the SCT signals is discussed.

2. Sensitivity Compensated Transmitting Signal

2-1 Sensitivity Compensated AM Signal

Neglecting noise, a received signal $F_r(\omega)$ can be expressed as $F_t(\omega)\cdot R(\omega)$, where $F_t(\omega)$ and $R(\omega)$ are transmitting signal and transfer function which mainly consists of the sensitivities of transducers.

Then, if we use a transmitting signal with an amplitude characteristic of the spectrum as $|R(\omega)|^{-1}$, a signal with flat spectrum can be received. In our study, the SCAM signal $F_{ta}(\omega)$ can be calculated by reference received signal $|F_{r0}(\omega)|$ and $F_t(\omega)$ as

$$F_{ta}(\omega) = \frac{|F_{r0}(\omega)|}{|F_{r0}(\omega)|^2 + \alpha^2 \cdot |F_{r0}(\omega)|^2_{\max}} \cdot F_t(\omega) \tag{1}$$

where α is a stabilization factor limiting the divergence of the response function where the value of $F_{r0}(\omega)$ is small. In this paper, considering of the SNR and the effective band width, α=0.03 (-30 dB from the maximum) is employed.

2-2 Sensitivity Compensated FM Signal

The SCFM signal $S_{tf}(t)$ can be calculated according to Parseval's theorem. In Parseval's theorem, energy of $F_{ta}(\omega)$ and energy of $S_{tf}(t)$ should be identical. In frequency bandwidth $\Delta\omega$, it is written as

$$|F_{ta}(\omega)| \cdot \Delta\omega = S_{tf}(t) \cdot \Delta t \tag{2}$$

where A and $\Delta t(\omega)$ are amplitude (constant) and duration time corresponding to $\Delta\omega$ on the wave form $S_{tf}(t)$. Eq(2) can be transformed as

$$t(\omega) = \frac{1}{A^2} \cdot \int_0^{\omega} |F_A(\Omega)|^2 d\Omega \tag{3}$$

Then, $t(\omega)$ is replaced with $\omega(t)$, and SCFM signal is given as

$$S_{tf}(t) = A^2 \cdot \sin\left[\int_0^t \omega(\tau) d\tau\right] \tag{4}$$

3. Direction Measurement and Pulse Compression

For direction measurement, a transmitter and two receivers are arranged as shown in Fig. 1. The transmitter and the receivers are arranged parallel with a 50 mm interval, and the target is a 70 × 70 mm square steel plate. Here, L and L' are the distances from the target to the receivers respectively, and D is the interval of receivers.

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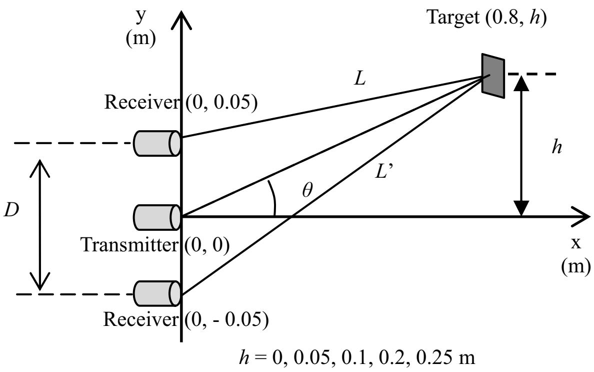


Fig. 1 Arrangement of transducers for direction measurement

Here, if $D << L$, direction θ can be approximately calculated as

$$\theta = \sin^{-1}\frac{|L-L'|}{D} \tag{5}$$

Considering the SNR, the matched filtering is employed for pulse compression. The compressed pulse $F_p(\omega)$ is calculated as

$$F_p(\omega) = F_{r0}^*(\omega)\cdot F_r(\omega) \tag{6}$$

where $F_{r0}^*(\omega)$ denotes the complex conjugate of the reference signal $F_{r0}(\omega)$, and $F_r(\omega)$ is the measured echo signal to be compressed.

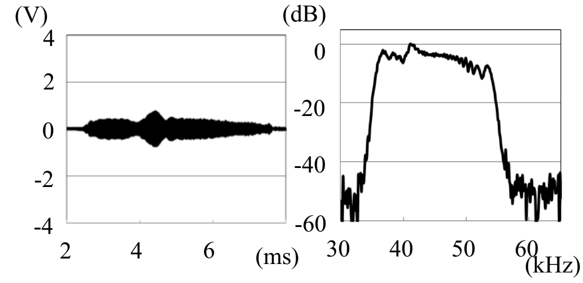
The reference signal is measured with direct transmitting-receiving arrangement. The transmitter with 10 mm diameter and a 40 kHz resonant peak; the receiver with 7 mm diameter and a comparatively wide band sensitivity are employed, and the transducers are placed with a distance of 0.2 m.

The direction measurement using the SCT signals are compared with that using the chirp wave.

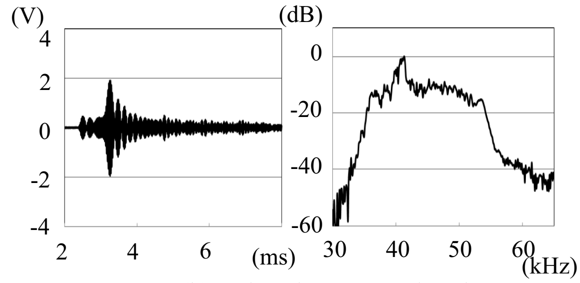
4. Results of Experiment

The SCT signals are calculated from the chirp wave and the reference signal of the chirp wave. The reference signal of the SCT signals are shown in Fig.2.

With arrangement of fig.1, direction measurement using the chirp wave and the SCT signals are compared. The angle is measured 20 times with the target placed at each location of h, and errors of deviation are calculated. The accuracies of direction measurement are shown in Fig.3. The tendency of improvement by using the SCT signals is acquired, comparing with that using the chirp wave. Particularly, direction measurement using the SCFM signal is improved from that using the SCAM signal, especially at the positions where the SNR is lower.



(a) Using the SCAM signal



(b) Using the SCFM signal

Fig.2 Reference signals of the SCT signals

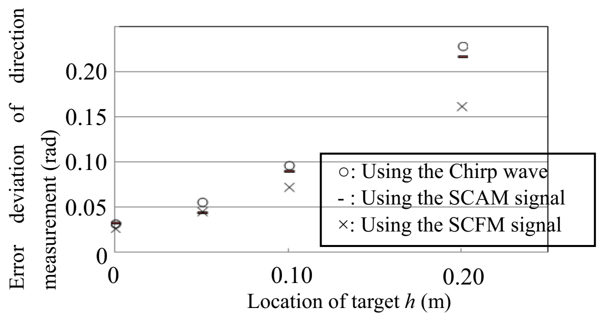


Fig.3 Accuracies of direction measurement

4. Conclusions

The sensitivity compensated transmitting signals that expanding bandwidth of received signal is proposed. The effectiveness of the direction measurement using the SCT signals is studied experimentally. The accuracies of direction measurement are improved by using the SCT signals. Furthermore, the accuracies of that using the sensitivity compensated FM signal are improved than that using the sensitivity compensated AM signal.

Acknowledgment

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References

1. J. Klabold, J. Rautenberg, et al: Pros. IEEE Int. Conf., pp.323-438 (2002).
2. R. Toh, S. Motooka: Jpn. J. Appl. Phys. **44** (2007) 07GB09.
3. D. Chimura, R. Toh, and S. Motooka. Proc. Natl. Autumn Meet. Acoustical Society of Japan, 2008, No. 2-Q-28 [in Japanese].
4. D. Chimura, R. Toh, and S. Motooka. J. Marine Acoust. Jpn. Vol 38 No. 2. (2010) [in Jpanese].