Direction Measurement in Air Using Sensitivity Compensated Signal and Pulse Compression

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Abstract - Ultrasonic pulse-echo method is widely employed for acoustical measurement in ocean or remote sensing in air such as automobiles and robots. Time-of-flight (TOF) is usually employed for target ranging. In order to acquire TOF with higher accuracy, pulse compression method is usually employed. For high-resolution measurement, frequency-modulated (FM) signal is used as transmitting signal. However, owing to sensitivities of the ultrasonic transducers, the spectrum of the received pulse echo signal will be uneven and narrow-banded. In order to acquire the received pulse echo signal with broader and flatter spectrum, we have proposed sensitivity compensated (SC) transmitting signal. The SC transmitting signal is calculated from the inversed spectrum of a measured signal, which is mainly influenced by sensitivities of the ultrasonic transducers. Using the SC signal as transmitting signal, it is expected that the signal with broader and flatter spectrum will be received. In this paper, the efficiency of pulse compression method using the SC signal for 2-D direction measurement is studied experimentally. A transmitter and two receivers are arranged for direction measurement. The direction of the target is calculated by measured TOF from two receivers. Comparison of the traditional linear FM transmitting signal (Chirp wave) and SC transmitting signal is discussed. The results of efficiency of pulse compression show that the pulse width of compressed signal derived by using SC transmitting signal is shortened to be about 1/5 of that by using the Chirp wave. The accuracies of direction measurement using SC signal are improved slightly than that of using the Chirp wave.

Index Terms – Sensitivity compensated signal, frequency modulation, pulse compression, ultrasonic pulse echo

I. Introduction

Ultrasonic pulse-echo method has been studied for applications such as, remote sensing robot and industrial robot [1], [2]. Time of flight (TOF) is usually employed for target ranging. For TOF method with high accuracy, pulse compression is employed. Frequency modulated (FM) transmitting signal is usually employed for high resolution measurement. However, owing to the sensitivities of ultrasonic transducers, received pulse echo signal will be uneven and narrow banded, that lessens the effectiveness of pulse compression. In order to acquire the received pulse echo signal with broader and flatter spectrum, a sensitivity compensated (SC) signal is proposed [3]. The SC signal is calculated from a measured signal which is mainly influenced by the sensitivities of ultrasonic transducers. Using the SC signal as a transmitting signal, it is expected that the received signal will have a broader and flatter spectrum.

For target detection, we have studied efficiency of pulse compression technique using the SC signal for 1-D target ranging and speed measurement [4]. In this paper, 2-D direction measurement using pulse compression and the SC signal is discussed.

II. Sensitivity compensated Signal and Pulse Compression

A. Sensitivity Compensated Signal

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

$$F_r(\omega) = F_t(\omega) \cdot R(\omega) \tag{1}$$

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. Theoretically, the ideal transmitting signal can be calculated by

$$\frac{|F_t(\omega)|}{|F_r(\omega)|} = \frac{1}{|R(\omega)|} \tag{2}$$

In our study, the sensitivity compensated signal $F_{ta}(\omega)$ can be calculated by reference received signal $|F_{r0}(\omega)|$ and $F_t(\omega)$ as

$$F_{ta}(\omega) = \frac{|F_{r0}(\omega)|}{|F_{r0}(\omega)|^2 + \alpha^2 \cdot |F_{r0}(\omega)|^2_{\max}} \cdot F_t(\omega) \tag{3}$$

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.

B. Pulse Compression

The matched and inverse filters are two typical signal-processing methods employed for pulse compression. The matched filter increases the SNR by multiplication, which amplifies the part of spectrum with higher amplitude, while the inverse filter increases the resolution by division, which compensates for the unevenness of the spectrum. In our work, an inverse filter is used for pre-processing to calculate the SC signal, and it is expected that a signal with a broader and flatter spectrum will be received. then, the matched filter is employed as post-processing for pulse compression.

The compressed pulse $F_p(\omega)$ is calculated by

$$F_p(\omega) = F^*_{r0}(\omega) \cdot F_r(\omega) \tag{4}$$

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

III. Conditions of Experiment

A. Transmitting Signal and Reference Signal

The SC signal is given from the chirp wave and the reference signal of the chirp wave. The reference received signal of Chirp wave, influenced mainly by the sensitivities of the transducers, is measured with direct transmitting-receiving arrangement shown in Figure 1. Here, the transmitter with 10 mm diameter and a 40 kHz resonant peak, receiver with 7 mm diameter and a comparatively wide around sensitivity are employed, and the transducers are placed with a distance of 0.2 m.

A frequency range of the Chirp wave is determined to be from 35 kHz to 55 kHz, and the pulse width of the waveform is 5 ms, and its spectrum between about 36 kHz to 53 kHz is nearly flat. While, as shown in fig. 2, because the sensitivities of transducers, the reference signal using the chirp wave is uneven and narrow-banded. The SC signal, calculated from the chirp wave and the reference signal using the chirp wave is shown in fig. 3. Because the SC signal is calculated from inversed filtering of fig. 2, the reference signal using the SC signal has broader and flatter spectrum as shown in fig. 4.

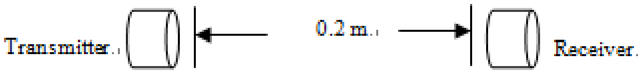
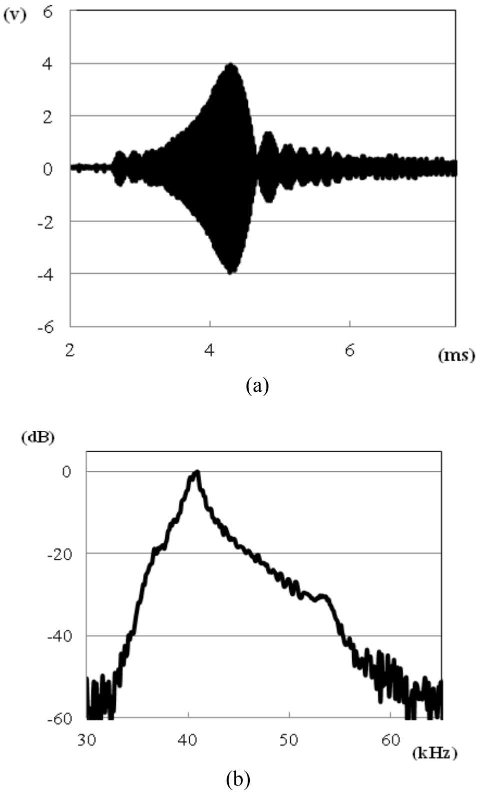


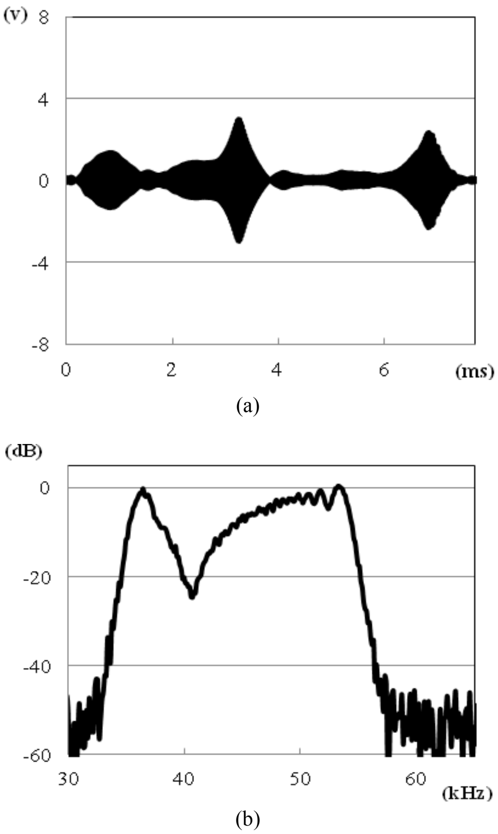
Fig. 1 Arrangement of transducers for reference signal measurement



(a)

(b)

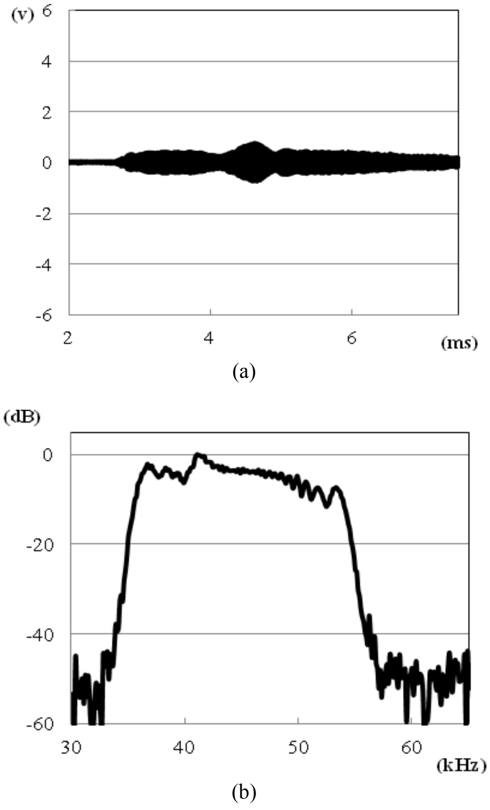
Fig. 2 Reference signal using the chirp wave (a) wave form (b) spectrum



(a)

(b)

Fig. 3 The SC signal (a) wave form (b) spectrum



(a)

(b)

Fig. 4 Reference signal using the SC signal (a) wave form (b) spectrum

B. *Direction Measurement*

For direction measurement, a transmitter and two receivers are arranged as shown in fig. 5. 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. If $D << L$, direction θ can be approximately calculated as

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

The direction measurement using the SC signal is compared with that using the chirp wave.

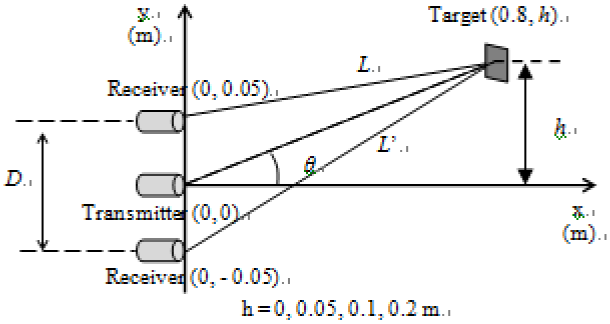
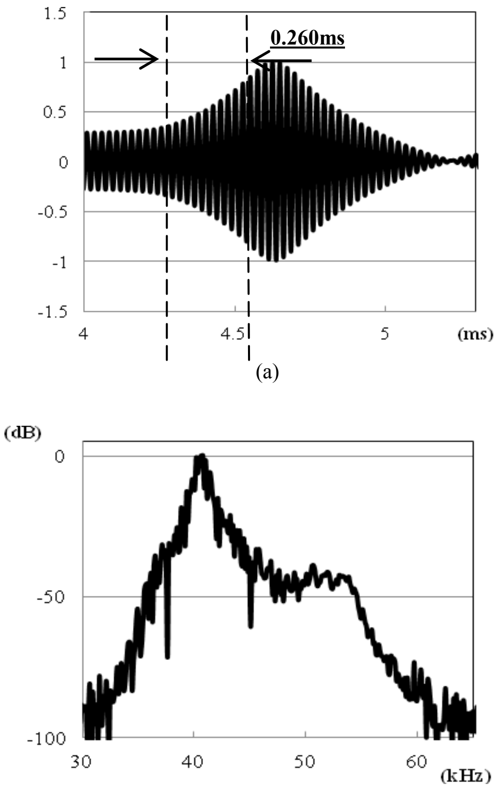


Fig. 5 Arrangement of transducers for direction measurement



(a)

(b)

Fig. 6 example result of pulse compression using the chirp wave (a) wave form (b) spectrum

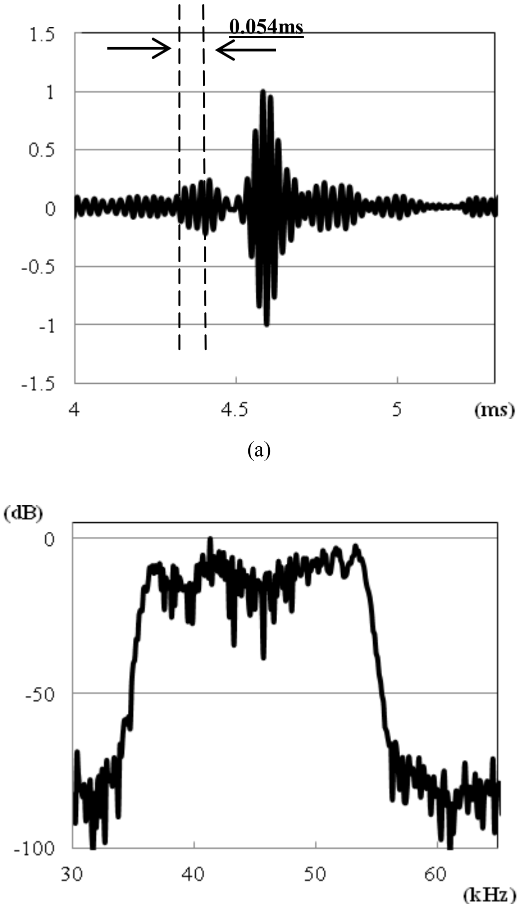
IV. Results of Experiment

The example pulse compression signal when h = 0 m using the chirp wave and that of using the SC signal are shown in fig. 6 and 7, respectively. The -3 dB pulse width corresponding to the chirp wave and the SC signal are 0.260 ms and 0.054 ms, respectively. Because the broader and flatter signal is received, pulse width is shortened to be about 1/5 for the SC signal.

With the arrangement of Fig. 5, direction measurement using the chirp wave and the SC signal as transmitting signal, is compared. The direction is measured 10 times with the target placed at each location of h, and the errors of deviation (E_t) are calculated as follows. Here, N is the number of measurements, θ is the direction, and θ_m is the direction calculated from the measurement.

$$E_t = \sqrt{\frac{\sum_{m=1}^{N}(\theta_m - \theta)^2}{N}} \tag{6}$$

The results are shown in Fig. 8. As shown, the accuracies of direction measurements using the SC signal are improved from that using the chirp wave. It suggests that TOF with higher accuracy is acquired by using the SC signal.



(a)

(b)

Fig. 7 example result of pulse compression using the chirp wave (a) wave form (b) spectrum

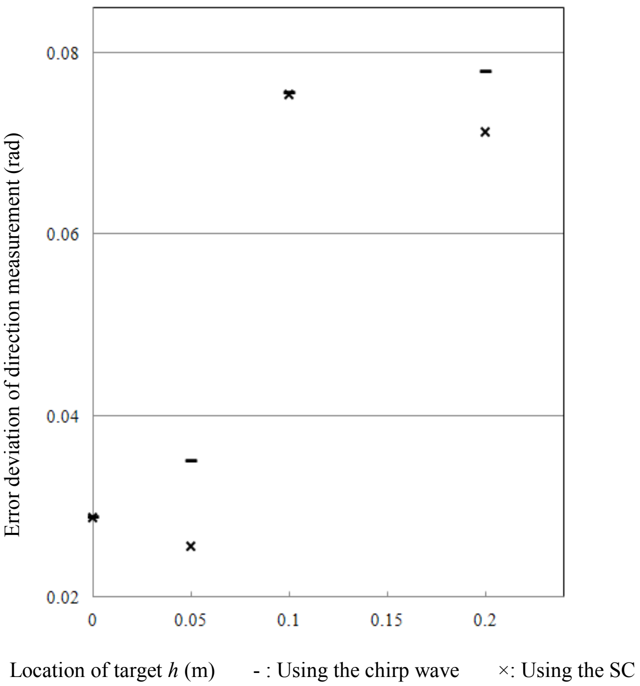


Fig. 8 accuracies of direction measurement

V . Conclusions

A method of expanding bandwidth by using the sensitivity compensated signal for high-resolution measurement is introduced. The effectiveness of the direction measurement using pulse compression is studied experimentally.

Comparing to using the chirp wave, the pulse width is shortened to be about 1/5 by using the SC signal. The accuracies of direction measurement are improved slightly.

References

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