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Ultrasonic Target Ranging in Water by Using Sensitivity Compensated Signal and Time Reversal Method
感度補正信号と時間反転法を併用した水中超音波距離測定

Dai Chimura‡, Ryo Toh and Seiichi Motooka (Facult. Eng., Chiba Inst. Tech.)
千村　大‡，陶　良，本岡誠一 (千葉工大・工)

1. Introduction

Ultrasonic pulse-echo method using Time-of-flight (TOF) is used for target detection in various fields such as air, water and soil. Pulse compression method is usually employed for higher accuracy TOF measurement. Then, for high resolution measurement, linear frequency modulated singal (Chirp wave) is often used as transmitting signal. However, owning to sensitivities of the ultrasonic transducers, the efficiency of pulse compresion is limitted.

A Sensitivity Compensated Transmitting (SCT) signal has been proposed for higher resolution measurement[1]. The SCT signal is calculated from the Chirp wave and the inversed filtering of the received signal wich is mainly influenced by sensitivities of transducers. Therefore, by using the SCT signal, signal with broader and flatter spectrum can be received. We have proposed two types SCT signals (Sensitivity Compensated AM : SCAM signal and Sensitivity Compensated FM : SCFM signal) and target detection by using SCT signals such as target ranging and direction measurement have been stadied[2,3].

On the other hands, in underwater acousitics, Time Reversal (TR) method is employed for compensating phase distorsions owning to multipath propagation[4]. By transmitting the TR wave of the received signal form received point, the singal is focused to sound source point.

Here, cosidering reciprocating propagation, a Sensitivity Compensated for Time Reversal (SCTR) signal is proposed for measurement with higher resolution and Signal-to-noise ratio (SNR). The SCTR signal is caluculated from non-linear frequency modulation and amplitude modulation. In this paper, target ranging in water by using the SCTR signal with TR method is discussed.

2. Time Reversal Method

Received signal is expressed, by transmitted signal $F_t(\omega)$ and the effectiveness of scattering on propagation $H(\omega)$, as $H(\omega)\cdot F_t(\omega)$. The TR wave is phase conjugation, which expressed as $\overline{H(\omega)\cdot F_t(\omega)}$. Because the time reversal wave is transmitted form received point, the signal is focused to sound source.

$$H(\omega)\cdot\overline{H(\omega)\cdot F_t(\omega)} = |H(\omega)|\cdot\overline{F_t(\omega)}. \quad (1)$$

3. Sensitivity Compensated Transmitting Signal

3.1. Sensitivity Compensated FM Signal

Neglecting noise, a reference received signal $F_{R0}(\omega)$ can be expressed, by the product of the transmitting signal $F_T(\omega)$ and the transfer function $R(\omega)$, as $F_R(\omega) = F_T(\omega)\cdot R(\omega)$. Here, if we use a transmitting signal with the amplitude characteristic of $|R(\omega)|^{-1}$, a signal with a flat spectrum can be received. Then, Sensitivity Compensated spectrum $F_A(\omega)$ is given as

$$F_A(\omega) = \frac{|F_{R0}(\omega)|}{|F_{R0}(\omega)|^2 + \alpha^2\cdot|F_{R0}(\omega)|^2_{max}}\cdot F_T(\omega), \quad (2)$$

where α is a stabilization factor limiting the divergence of the response function.

A non-linear FM signal $S_{SA}(t)$ that equalized the spectrum of the amplitude characteristics with $|F_A(\omega)|$ is proposed[3]. According to Parseval's theorem, the energy of $F_A(\omega)$ and the energy of $S_{SA}(t)$ should be identical. Then, $t(\omega)$ can be calculated as Eq.(3).

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

Where A is amplitude of $S_{SA}(t)$. By replacing $t(\omega)$ with $\omega(t)$, the SCFM signal is given as

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

Here, considering reciprocating propagation at TR method, sensitivity compensation squared is employed for SCT signal.

3.2. Sensitivity Compensated for Time Reversal Signal

For TR method with higher resolution and SNR, the SCTR signal $F_{CA}(\omega)$ is proposed. $F_{CA}(\omega)$ is calculated by $F_A(\omega)$ and the spectrum of the SCFM signal $F_{SA}(\omega)$, given as

$$F_{CA}(\omega) = \frac{|F_{R0}(\omega)|}{|F_{R0}(\omega)|^2 + \alpha^2\cdot|F_{R0}(\omega)|^2_{max}}\cdot F_{SA}(\omega). \quad (5)$$

$F_{CA}(\omega)$ becomes the amplitude modulated SCFM signal, therefore, the amplitude of the TR wave will be identical in time domain waveform.

Email : chimura.dai@it-chiba.ac.jp

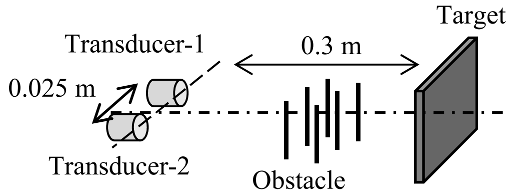

Fig.1 Arrangement for TR measurement

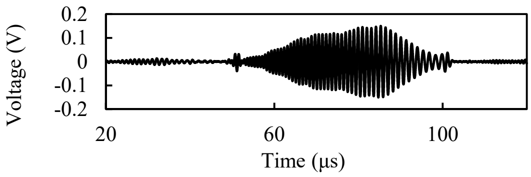

Fig.2 TR wave using Chirp wave

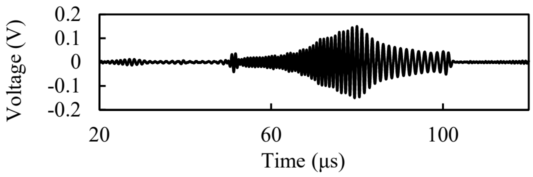

Fig.3 TR wave using SCFM signal

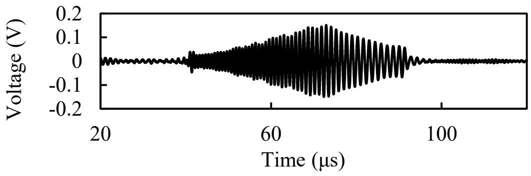

Fig.4 TR wave using SCTR signal

4. Experimental Condition

For the SCTR signal derivation, the reference signal is measured with a direct transmitting-receiving arrangement (distance of 0.2 m). The chirp wave with 0.5 ~ 1.5 MHz bandwidth is transmitted, and a water tank is employed for the measurement.

The arrangement for the TR measurement is shown in Fig.1. Transducers are arranged parallel with a 0.025 m interval, and the target is a steel plate. For the obstacle, 30 nails are arranged. The chirp wave, the SCFM signal and the SCTR signal are employed for the TR measurement. Each signal is transmitted form Transducer-1 and the received signal is measured with Transducer-2. Then, the TR wave is transmitted from Transducer-2 on the return propagation. And the received TR wave is applied cross-correlation. Here, a peak-to-peak amplitude of 600 mV is employed for each TR wave.

5. Results

Figs.2, 3 and 4 show the TR wave of each transmitting signal. By using the SCTR signal, the improvement of SNR is seen comparing with that using the SCFM signal. Because the sensitivity compensation is occurred by AM and FM, the wave

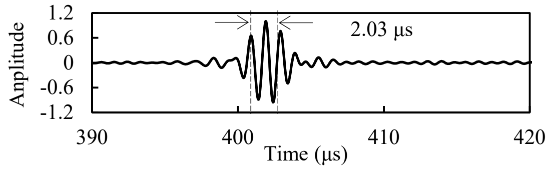

Fig.5 Compressed pulse using Chirp wave

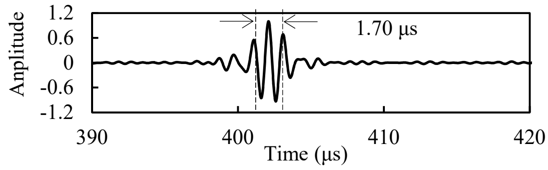

Fig.6 Compressed pulse using SCFM signal

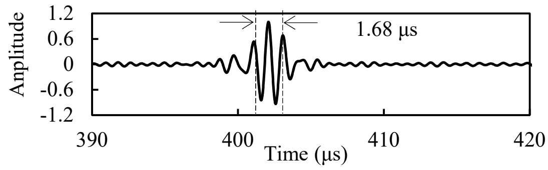

Fig.7 Compressed pulse using SCTR signal

form of the TR wave using the SCTR signal is compensated than that of using the SCFM signal.

Figs.5, 6 and 7 show the cross-correlation signal using each signal. Pulse widths of the envelope curve at -3 dB corresponding to the Chirp wave, the SCFM signal and the SCTR signal are 2.03, 1.70 and 1.68 µs, respectively. Because the sensitivity compensation, the pulse width using the SCTR signal is shortened than that of using the Chirp wave.

6. Conclusions

For higher resolution and higher Signal-to-noise ratio (SNR) Time Reversal (TR) measurement, the Sensitivity Compensated for Time Reversal (SCTR) signal is proposed, and target ranging using the SCTR signal and TR method is studied experimentally.

By using the SCTR signal, TR measurement with high resolution and high SNR can be expected.

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