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Speed Measurement by Using Sensitivity Compensated FM Signal
感度補正 FM 変調信号を用いた速度計測

Dai Chimura†, Ryo Toh and Seiichi Motooka (Chiba Institute of Technology)
千村大†，陶良，本岡誠一 （千葉工業大学）

1. Introduction

As target ranging methods, ultrasonic pulse echo is widely used for remote sensing. For high accuracy measurement, pulse compression technique is often used.[1] Here, effect of pulse compression is influenced by signal bandwidth. To acquire broad band signal, we proposed method of target ranging by using sensitivity compensated frequency modulated (SCFM) signal as transmitting signal.[2,3] SCFM signal is a non linear frequency modulated chirp wave, with the compensated amplitude of spectrum for the sensitivities of transducers. By considering the sensitivities of transducers, the spectrum of receiving signal can be expected to be broader and flatter.

On the other hand, method using doppler shift of freuency is commonly used for speed measurement. However, owning to the resolusion of the frequency shift, the measureable lower speed is limited.

Therefore, we propose a mothod of speed measurement by high accuracy target ranging using SCFM signal. Speed of moving target is calculated from the interval of transmitting two pulses and that of the corresponding receiving pulses.

In this paper, the effectiveness of SCFM signal in speed measurement is studied.

2. Sensitivity Compensate FM signal

Neglecting the noises, receiving 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 consists of the sensitivities of transducers. Therefore, if we use transmitting signal with an amplitude characteristic of the spectrum as $|R(\omega)|^{-1}$, signal with flat spectrum can be received. The sensitivity compensated signal $F_A(\omega)$ calculated by inverse filtered receiving signal is given as

$$F_A(\omega) = \frac{|F_r(\omega)|}{|F_r(\omega)|^2 + \alpha^2 \cdot |F_r(\omega)|^2_{max}} \cdot F_t(\omega) \qquad (1)$$

Where α is the stabilization factor to restrain the divergence of the response function at where the value of $F_A(\omega)$ is small.

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

$$|F_A(\omega)|^2 \cdot \Delta\omega = A^2 \cdot \Delta t(\omega) \qquad (2)$$

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

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

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

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

Hence, the amplitudes of spectrum of SCFM signal is compensated by non linear frequency modulation, approximately to be that of $F_A(\omega)$.

3. Experiment methods and conditions

3-1 Pulse compression and speed measurement

Pulse compression using matched filter, which optimizes the SNR is employed. The compressed signal $F_p(\omega)$ is calculated by the received signal $F_r(\omega)$ and reference signal $F_0(\omega)$. It is written as

$$F_p(\omega) = F_r(\omega) \cdot F_0^*(\omega) \qquad (5)$$

Where $F_0^*(\omega)$ is the complex conjugate of $F_0(\omega)$.

For speed measurement, a transmitting signal consisting of two SCFM pulses with an interval τ_0 is employed. Considering interval d of transmitter and receiver, and the distance R between the target and the center of the transducers, if d<<$2R$, speed of target v can be approximately calculated as

$$v = \frac{\tau_0 - \tau_r}{\tau_0 + \tau_r} \cdot \cos\left(\tan^{-1}\frac{d}{2R}\right) \cdot c \qquad (6)$$

Where τ_r is an interval of received two pulses and c is the sound velocity.

3-2. Conditions of experiment

To acquire reference signal and SCFM signal, considering majorly the sensitivities of the transducers, we align two transducers, facing to each other with a distance of 20 cm, as shown in Fig.1. Here, two transducers with a 1.5 cm diameter

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† Email: s0322221XU@it-chiba.ac.jp

and a 40 kHz resonant peak are employed.

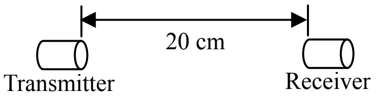


Fig.1 Arrangement of transducers for reference signal and SCFM signal measurement

Fig.2 shows the arrangement of the transducers and the moving target for speed measurement. The transmitter and receiver are arranged parallel to each other with a 10 cm interval, and a 7 cm ×7 cm square steel plate is employed as target. The transmitting signal is triggered when the target is moving to about 250 cm from center of the transducers. Target is moved on a rail-robot speed control system. Measuring the speed using chirp wave and SCFM signal, we compare accuracies of each measurement. Here, the interval of transmitting two pulses is 8 ms.

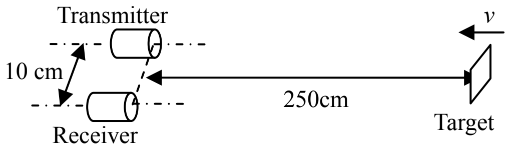


Fig.2 Arrangement for speed measurement

4. Results of Measurement

4-1. Reference signal and SCFM signal

Fig.3 shows the chirp wave, which pulse width of the waveform is 5 ms, and the frequency is modulated from 35 kHz to 55 kHz. Fig.4 shows reference signal using chirp wave. Although the spectrum of chirp wave is approximately flat, the spectrum of reference signal is influenced by sensitivities.

Fig.5 shows the SCFM signal, calculated from the chirp wave and the reference signal using chirp wave shown in Fig.3 and Fig.4. Fig.6 shows reference signal using SCFM signal. The spectrum of SCFM signal is compensated for by the sensitivities of transducers with a non linear frequency modulation, and therefore, the spectrum of reference signal using SCFM signal is broader and flatter than that using chirp wave.

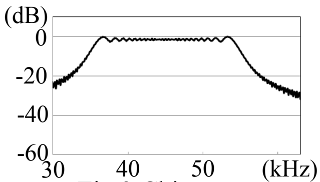


Fig.3 Chirp wave

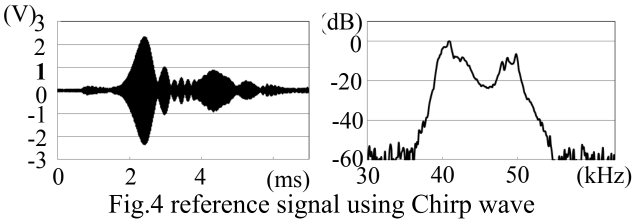


Fig.4 reference signal using Chirp wave

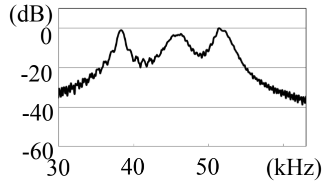


Fig.5 SCFM signal

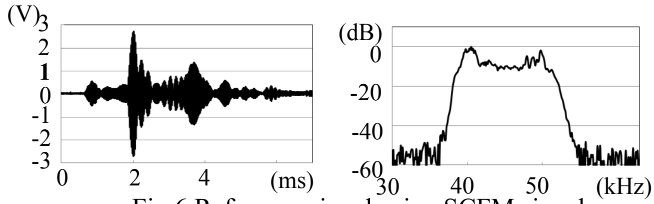


Fig.6 Reference signal using SCFM signal

4-2. Speed measurement

Examples of pulse compression signal using each transmitting signal when v=1.2 m/s are shown as Fig.7 (a) and (b). In Fig.7, τ_r of (a) and τ_r of (b) are 7.948 ms and 7.944 ms, therefore, speed calculated by Eq(6) are 1.13 m/s and 1.21 m/s respectively.

Fig.8 shows error deviation of 10 measurements at each speed. It shows that accuracies of speed measurement using SCFM signal are higher than that using chirp wave.

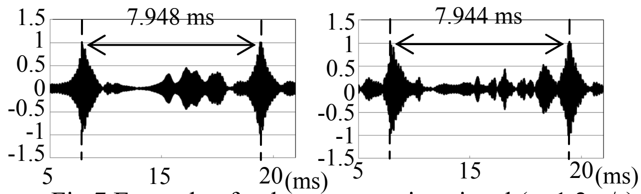
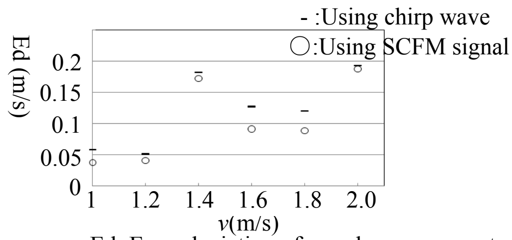


Fig.7 Example of pulse compression signal (v=1.2m/s)
(a) Using chirp wave (b) Using SCFM signal



Ed: Error deviation of speed measurement
Fig.8. Accuracies of speed measurement

5. Conclusions

By using SCFM signal, receiving signal with broader and flatter spectrum is acquired. Moreover, accuracies of speed measurement are higher than using chirp wave. These results indicate that effectiveness of the SCFM signal in speed measurement can be expected.

References

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