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Speed Measurement Using Sensitivity Compensated Signal with Linear Prediction -Band Expanding by Using ARMA Model-
感度補正型信号と線形予測法を併用した速度計測法 -ARMA モデルによる信号帯域の拡大-

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 widely used for target detection in air such as robots and automobiles[1]. Then, pulse compression method is usually employed for TOF measurement with higher accuracy.

For high-resolution measurement, frequency-modulated (FM) signal is used as transmitting signal. However, owning to sensitivities of the ultrasonic transducers, the spectrum of the received signal will be uneven and narrow-banded. In order to acquire the recived signal with broader and flatter spectrum, Sensitivity Compensated Transmitting (SCT) signal has been proposed[2]. The SCT signal is calculated from a linear FM signal (Chirp wave) and a inversed filtering of the measured signal which is mainly influenced by the sensitivities of ultrasonic trancducers. Here, because the SCT signal becomes an amplitude-modulated chirp wave, we call the SCT signal a Sensitivity Compensated Anplitude-modulated (SCAM) signal.

Considering the signal with flatter spectrum by using the SCAM signal, we have proposed band expanding method by using linear prediction[3]. The predicted values calculated from the linear prediction (LP) processing using the flatter spectrum with higher SNR compensate the spectrum with lower signal-to-noise-raitio (SNR). Thus the time resolution of the signal can be improved. We have proposed target detection method such as target ranging and speed measurement of moving target by using the SCAM signal and LP with Auto Regressive (AR) model[4].

In this paper, we propose a method of band expanding by using LP with Auto Regressive Moving Average (ARMA) model. And speed measurement using the SCAM signal with band expanding by using ARMA model is discussed.

2. Sensitivity Compensated Amplitude Modulated 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.

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

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

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, $\alpha = 0.03$ is employed.

3. Linear Prediction Processing

For expanding the spectrum bandwidth, we propose a method of compensation of the spectrum with lower SNR by using a predicted value calculated from LP processing. The predicted value is calculated by LP coefficients derived from the flatter spectrum with higher SNR. Because the predicted value compensates the spectrum with lower SNR, the signal with higher time resolution can be expected. In this paper, two type of LP models are compared.

3-1 Auto regressive model

In AR model, predicted value $F_L(\omega)$ is calculated from a linear combination of the previous value and a AR coefficient a_i as shown in Eq.(2). Where p and $e(\omega)$ are AR order and prediction error.

$$F_L(\omega) = -\sum_{i=1}^{p} a_i \cdot F_L(\omega - i) + e(\omega) \quad (2)$$

Here, a_i can be derived from normal equation of auto-correlation function $\varphi(\omega)$ of $F_L(\omega)$ as

$$\begin{bmatrix} \varphi(0) & \varphi(1) & \cdots & \varphi(p-1) \\ \varphi(1) & \varphi(0) & \cdots & \varphi(p-2) \\ \vdots & \vdots & & \vdots \\ \varphi(p-1) & \varphi(p-2) & \dots & \varphi(0) \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_3 \end{bmatrix} = -\begin{bmatrix} \varphi(1) \\ \varphi(2) \\ \vdots \\ \varphi(p) \end{bmatrix} \quad (3)$$

3-2 Auto regressive moving average model

In ARMA model, $F_L(\omega)$ is calculated from the linear combination of previous value and the linear combination of $e(\omega)$ as shown in Eq.(4). Where, q and b_i are Moving Average (MA) order and MA coefficient. Here, we apply the normal equation to

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chimura.dai@it-chiba.ac.jp

the derivation of q and b_i. In this paper, a_i=150 and b_i=3600 are employed.

$$F_{\mathrm{L}}(\omega) = -\sum_{i=1}^{p} a_i \cdot F_{\mathrm{L}}(\omega - i) + \sum_{i=1}^{q} b_i \cdot e(\omega - i) \quad (4)$$

4. Speed Measurement Method

A cross-correlation of the received signal and the reference signal is employed for pulse compression.

The reference signal using the chirp wave for the SCAM signal calculation is measured with direct transmitting-receiving arrangement (the interval is 0.2m). And the reference signal using the SCAM signal for pulse compression as shown in Fig.1 is measured.

For speed measurement, a transmitting signal consisting of two pulses with an interval τ_0 is employed. The arrangement for speed measurement is shown in Fig.2. Considering the interval d of transmitter and receiver placed parallel to each another, and the distance R between the target and the center of the transducers, if d<<2R, the speed of the target v can be approximately calculated as

$$v = \frac{\tau_0 - \tau_{\mathrm{r}}}{\tau_0 + \tau_{\mathrm{r}}} \cdot \cos\left(\tan^{-1}\frac{d}{2R}\right) \cdot c \qquad (5)$$

where τ_{r} is the interval of two pulses in received signal, c is the sound velocity.

As the target, a 70 mm × 70 mm square steel plate is employed and the target is moved on a rail-robot speed control system. The transmitting signal is triggered when the target is moving to about R=2.5m from the center of the transducers.

Speeds from 1.0 to 2.0 m/s with 0.1 m/s interval are measured 20 times at each speed.

5. Results

The accuracy of speed measurement using the SCAM signal with two type of LP processing is shown in Fig.3. As shown in Fig.3, accuracies of the speed measurement are improved about 0.01 m/s by using the SCAM signal with the ARMA model where target moves lower speed. It suggests that because the band expanding using the ARMA model, the TOF measurement with higher time resolution was obtained.

On the other hand, accuracies of speed measurement when the target moves higher speed is decreased by using the SCAM signal with the ARMA model. A reason of this result is considered to be that because the ARMA model consists of the complicated linear combination, the band expansion processing is more influenced by doppler frequency shift than that of using the AR model. Therefore, the efficiency of the band expansion is decreased. Also this band expansion processing needs to be studied such as the calculation of the LP coefficients.

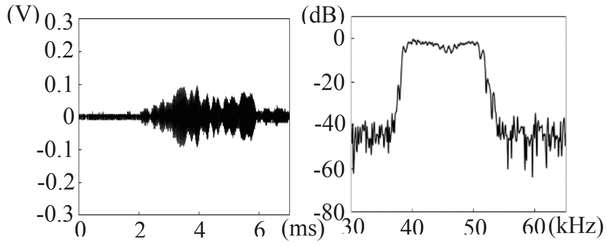

Fig. 1 Reference signal using the SCAM signal

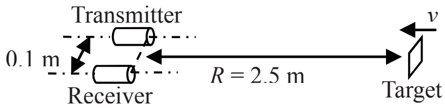

Fig. 2 Arrangement for speed measurement

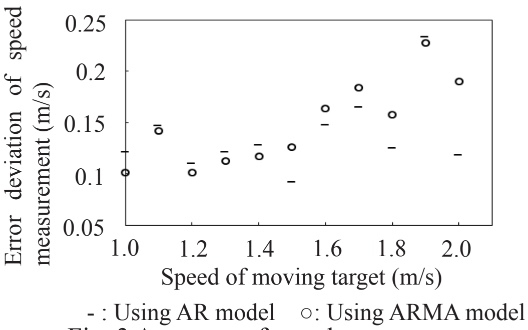

Fig. 3 Accuracy of speed measurement

6. Conclusions

For high accuracy ultrasonic pulse-echo measurement, a method of expanding bandwidth by using Auto-Regressive-Moving-Average model was proposed, and speed measurement using a Sensitivity-Compensated-AM signal with the band expansion was discussed.

As the result, the tendency of improvement of the accuracy of speed measurement at lower speed was indicated.

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