3J2-3

Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 297-298
13-15 November, 2012

Study about accuracy and resolution of ultrasonic distance and velocity measurement for moving objects using M-sequence modulated signals

M 系列変調信号を用いた移動物体の超音波距離速度計測の精度・分解能に関する検討

Shinnosuke Hirata[1‡] and Hiroyuki Hachiya[1] ([1]Tokyo Tech.)
平田慎之介 [1‡], 蜂屋弘之 [1] ([1] 東工大)

1. Introduction

Acoustic sensing is used for measurement of distance, velocity and shape in many industrial applications. The pulse-echo method is one of the typical methods of ultrasonic distance measurement. The pulse-echo method is based on determination of the time of flight (TOF) of an echo reflected from an object. In this method, the signal-to-noise ratio (SNR) of the reflected echo and distance resolution can be improved by transmition of the M-sequence modulated signal and correlation of the received signal wiht the transmitted signal[1)].

In the case of a moving object, however, the reflected echo is modulated due to the Doppler effect caused by the object's motion. Therefore, the reflected echo cannot be correlated with the transmitted signal. By correlation with a large number of reference signals, which are Doppler-shifted transmitted signals, distances and Doppler velocities of objects can be estimated from a large number of cross-correlation functions[2)]. However, this calculation requires high-cost digital signal processing.

Therefore, a novel method of Doppler velocity estimation before the collation process has been proposed. In the proposed method, the Doppler velocities are estimated from cepstrum of Doppler-shifted M-sequence modulated signals. Then, the received signal is correlated with several Doppler-shifted transmitted signals. The distance of each velocity's object is estimated from each cross-correlation function. In this report, accuracy and resolution of the proposed Doppler velocity estimation are evaluated based on computer simulations.

2. Principle of Doppler velocity estimation

M-sequence is maximum-length pseudo-random sequence, which is generated using a linear feedback shift register. Spectrum of 1 cycle of M-sequence is whiteness. However, spectrum of cycles of M-sequence is expressed as summation of delta functions, whose interval is inverse of the cycle length. Therefore, the peak time in cepstrum of cycles of M-sequence indicates the cycle length. In case cycles of M-sequence are Doppler-shifted, the cycle length is increased or decreased in proportion to the Doppler velocity. The Doppler velocity can be thus estimated from cepstrum of cycles of M-sequence.

In the proposed method, cosine wave of 40 kHz is modulated by 10th-order M-sequence, 1023 digits in 1 cycle. 3 cosine waves are assigned to 1 digit of M-sequence. The cycle length of M-sequence modulated signal is 76.725 ms, 3069 cosine waves of 40 kHz. Moreover, the length of transmitted signal, which is 2-cycles M-sequence modulated signal, is 153.45 ms. In case the sampling frequency and acoustic propagation velocity in air are 10 MHz and 343.5 m/s, resolution of signal processing in Doppler velocity estimation is approximately 0.22 mm/s.

3. Accuracy of estimated velocity in noisy environment

Accuracy of estimated velocity was examined by simulations. Parameters described above were also used in the simulations. In addition, analyzed signal was 2^{21} samples, which include 2-cycles M-sequence modulated signal of 1534500 samples. At first, spectrum of 2-cycles M-sequence modulated signal was computed by fast Fourier transform of the analyzed signal. Then, cepstrum was also computed by fast Fourier transform of the absolute values of spectrum. In this report, the peak time in cepstrum was determined as maximum peak time from 67.2 ms to 86.2 ms in the real parts of cepstrum. This range of the cycle length corresponds approximately to the Doppler velocity from -20 m/s to 22.7 m/s.

The SNR of analyzed signal was changed by adding Gaussian white noises. In case the SNR was greater than several dB, there was no error of estimated velocities. In case the SNR was 0 dB, there were velocity errors of ± 1 sample, as illustrated in **Fig. 1**. In addition, estimated Doppler velocities, when the SNRs were -10 dB and -20 dB, are also illustrated in **Figs. 2-3**. The standard

shin@ctrl.titech.ac.jp

deviations of estimated velocities are shown in **Table 1**. Distributions of velocity errors spread as the SNR of M-sequence modulated signal is lesser. Therefore, accuracy of the estimated velocity depends on the SNR of the analyzed signal. In case the SNR was lesser than -30 dB, furthermore, the peak time in cepstrum could not be determined.

4. Resolution of estimated velocity

Resolution of estimated velocity was examined by simulations. Analyzed signal was 2^{22} samples, which include 2-cycles M-sequence modulated

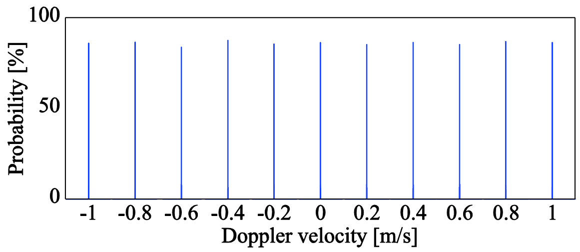

Fig. 1 In case the SNR was 0 dB, estimated Doppler velocities from maximum peak time in cepstrum.

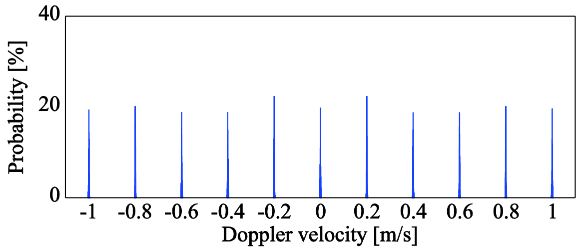

Fig. 2 In case the SNR was -10 dB, estimated Doppler velocities from maximum peak time in cepstrum.

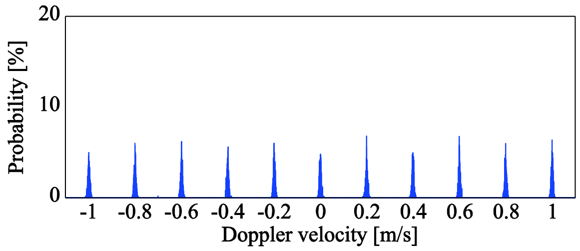

Fig. 3 In case the SNR was -20 dB, estimated Doppler velocities from maximum peak time in cepstrum.

Table 1 The standard deviations of estimated Doppler velocities when the SNRs were 0, -10 and -20 dB.

Doppler velocity [m/s]	Standard deviation [mm/s]		
	0 dB	-10 dB	-20 dB
-1	8.34×10^{-2}	0.615	4.64
-0.8	8.58×10^{-2}	0.616	5.27
-0.6	8.51×10^{-2}	0.603	4.52
-0.4	8.28×10^{-2}	0.635	4.09
-0.2	9.34×10^{-2}	0.567	6.85
0	7.94×10^{-2}	0.592	5.66
0.2	9.35×10^{-2}	0.593	5.28
0.4	7.88×10^{-2}	0.618	6.46
0.6	7.64×10^{-2}	0.589	6.42
0.8	7.44×10^{-2}	0.634	6.63
1	9.01×10^{-2}	0.577	6.72

signal and Doppler-shifted signal. The Doppler velocities were changed from 0.01 m/s to 0.06 m/s. Cepstrum around the peak times is illustrated in **Fig. 4**. In this report, the peak in cepstrum was determined as between its half values. In case the difference of Doppler velocities was greater than 0.03 m/s and the analyzed signal does not include noises, each Doppler velocity could be classified.

5. Conclusions

Doppler velocity estimation from cepstrum of cycles of M-sequence modulated signals has been proposed. In this report, estimated velocities in noisy environments are examined by computer simulations. In case the SNR is greater than -20 dB, the Doppler velocity can be estimated. In case a noise is not included in the analyzed signal. the difference of Doppler velocities, which was greater than 0.03 m/s, could be classified.

References

1. K. Nishihara, T. Yamaguchi, H. Hachiya: Acoust. Sci. & Tech. **29** [1] (2008) 15.
2. Y. Ito, T. Yamaguchi, H. Hachiya: IEICE Technical Report **108** [436] (2009) 17.

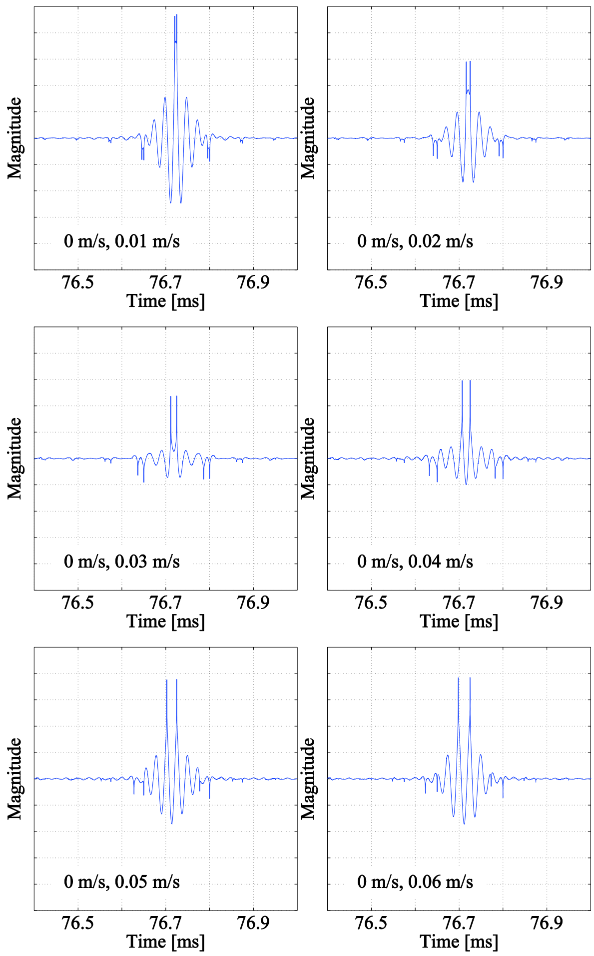

Fig. 4 Cepstrum around the peak times when the Doppler velocities from 0.01 m/s to 0.06 m/s.