3Pb2-4
Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 473-474
8-10 November, 2011

Examination of two-dimensional airborne ultrasonic position and velocity real-time measurement using chirp waves.

チャープ波を用いた実時間 2 次元超音波位置・速度計測に関する研究

Shinya Saito[1‡], Minoru Kuribayashi Kurosawa[1], Yuichiro Orino[1] and Shinnosuke Hirata[2]
([1] Tokyo Tech; [2]The University of Electro-communications)
齋藤 信弥 [1‡], 黒澤 実 [1], 折野 裕一郎 [1], 平田 慎之介 [2]([1] 東工大 総理工; [2] 電通大)

1. Introduction

Acoustic sensing systems are used in many industrial applications due to advantages of acoustic sensors, their low-purchase cost, small size, and simple hardware. 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. Pulse compression has been introduced in the pulse-echo method for improvement of the signal-to-noise ratio (SNR) of the reflected echo and distance resolution.

A linear-frequency-modulated (LFM) signal is used in the pulse-echo method. The frequency of LFM signal linearly sweeps with time. A received signal is correlated with a reference signal which is the transmitted LFM signal. The TOF of the transmitted signal is estimated by the maximum peak in the cross-correlation function of received signal and reference signal. The signal processing for cross-correlation consists of huge iterations of multiplications and accumulations. Therefore, real-time ultrasonic measurement is difficult because of the high cost in digital signal process. For reducing the calculation cost of pulse compression, a signal processing method using a delta-sigma modulated single-bit digital signal has been proposed [1].

When an object is moving, echoes are Doppler-shifted due to the Doppler-effect. Linear-period-modulated (LPM) signal is used in this research because the Doppler-shifted LFM signals cannot be correlated with the transmitted LFM signal. Pulse compression using LPM signals has been proposed for ultrasonic measurement of moving objects [2][3]. In this paper, two-dimensional (2D) ultrasonic position and velocity real-time measurement is examined by experiments and implementation in FPGA.

2. Experiment

The experimental setup for the ultrasonic position and velocity is illustrated in **Fig. 1.** In the experiment, the period of the transmitted LPM signal linearly swept from 20 μs to 50 μs, and the length of the LPM signal was 3.274 ms. A pair of LPM signals was transmitted by the loudspeaker [3], and the echo from the object was detected by two microphones. The received signals were converted into the single-bit delta-sigma modulated signals. The sampling frequency of the delta-sigma modulator was 12.5 MHz. The received signals were correlated with the reference signal using MATLAB on the computer. Therefore, this experiment was not real-time measurement.

The object was a plastic ball whose diameter was 17 cm. The distance and the angle from the loudspeaker to the object were 1.05 m and 20° respectively when the LPM signals were transmitted. The velocity of object was 0.4 m/s, the direction of movement was normal to a straight line that links microphones and the loudspeaker, φ=180° in Fig. 1. The measurement was executed 150 times.

The distribution of the position and the velocity vector are illustrated in **Fig. 2**. The standard deviation of the distance and angle were 73.8 μm and 0.09°, respectively. The standard deviation of the velocity and the direction angle were 0.038m/s and 10.9°,

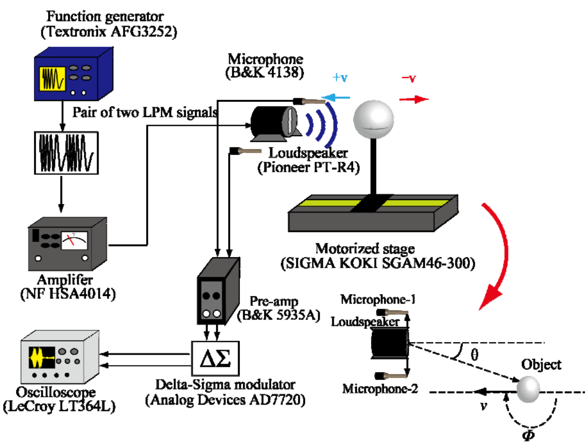

Fig.1 Experimental setup of 2D ultrasonic position and velocity vector measurement.

† saitou.s.aa@m.titech.ac.jp

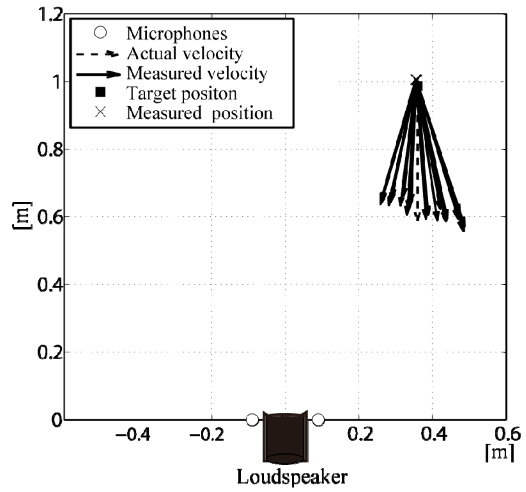

Fig. 2 Experimental result of 2D ultrasonic position and velocity vector measurement.

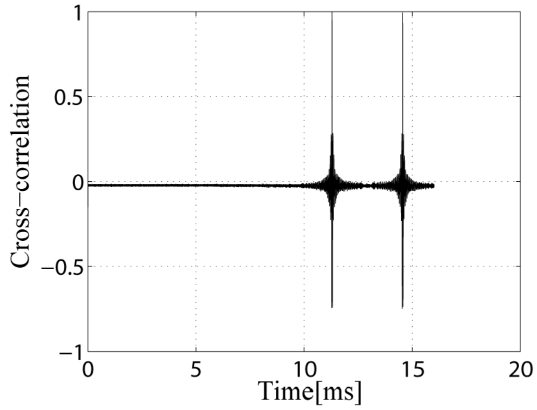

Fig. 4 Output signal of FPGA.

respectively. High accuracy regarding position measurement was obtained by experiments, but the standard deviation of the velocity vector measurement was a little large. The approximate value of the object's velocity vector could be estimated, but the measuring accuracy was required to improve slightly.

3. Implementation

The ultrasonic measurement was not real-time in experiments because the signal processing was executed on the computer. The signal processing is required to implement in FPGA for real-time measurement. So cross-correlation by single-bit signals was implemented in FPGA in this paper.

The signal process implemented in FPGA is illustrated in **Fig. 3**. A pair of LPM signals was generated by the function generator. The generated signals were converted into the single-bit delta-sigma modulated signals. The output signal of the delta-sigma modulator sets up the input signal of FPGA. The input signal of FPGA is stored in shift-register. The cross-correlation function is calculated using the zero-cross point of the reference signal, the input and output of the shift-register

The output signal of FPGA is illustrated in **Fig. 4**. The cross-correlation function executed on FPGA was equal to the cross-correlation function executed on the computer using MATLAB, and the cross-correlation function was obtained in real-time. The circuit size was 2,257 LEs, and the usage of RAM was 40,884 bit.

4. Conclusion

Accuracy of airborne ultrasonic 2D position and velocity vector measurements was examined by experiments. High accuracy regarding the position measurement was obtained. On the other hand, there was room for improvement regarding velocity vector measurement but the approximate value of the object's velocity vector can be estimated.

The signal processing was implemented in FPGA for real-time measurement. The cross-correlation function executed on FPGA was equal to the cross-correlation function executed on the computer using MATLAB. The implementation of signal processing showed the possibility of real-time measurement. For the future work, the peak detection of the cross-correlation using FPGA will be considered.

Reference

1. S. Hirata, M. K. Kurosawa, and T. Katagiri: IEICE Trans. Fundamentals **E91-A, No.4** (2008) p. 1031 - 1037.
2. J. J. Kroszczynski: Proc. of the IEEE, **Vol. 57, No.7** (1969) p. 1260 - 1266.
3. S. Hirata, M. K. Kurosawa, and T. Katagiri: Acoust. Sci&tech. **Vol. 30, No. 3** (2009) p. 180 – 186.

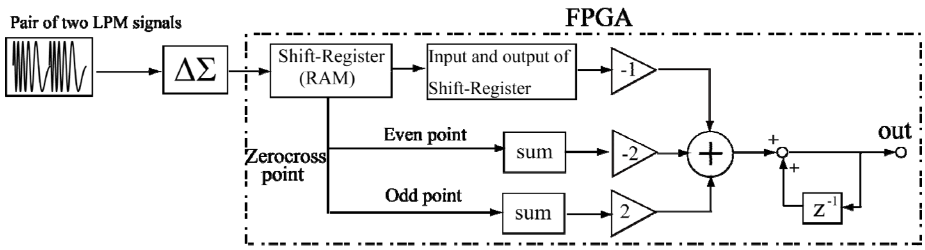

Fig. 3 Signal processing on FPGA.