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# Examination of three-dimensional airborne ultrasonic position real-time measurement using chirp wave

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## 1. INTRODUCTION

Acoustic sensing systems are available in many applications due to good points of acoustic device, namely, low-cost price, small size, and simple hardware. Especially in ultrasonic measurements, this type has been widely researched in a variety of applications. For the distance measurements that use ultrasonic waves, they can be applied because the structures easily reflect them. The pulse-echo method is one for the general ideas of ultrasonic distance measurement [1-2]. In general, this technique is relied on the determination of the TOF of an echo that is reflected from an object. Furthermore, pulse compression has been proposed in the pulse-echo method for signal-to-noise ratio (SNR) improvement of the reflected echo and distance resolution.

Chirp signals are an ingenious method of handing a practical problem in ultrasonic distance measurements. A linear-period-modulated (LPM) signal is one of chirp signals. Its period is swept linearly with time. It allows the cross-correlation function to determine TOF via the Doppler Effect [3]. One-dimensional ultrasonic distance measurements have been achieved using a speaker and a microphone [4-5]. Accuracy and resolution of distance measurements are given using a delta-sigma modulation. Because it is an over sampling method, a huge amount of samples is required. It is directly effective to the computational time cost of cross-correlation function. To make it possible in real-time works, the cross correlation function based on one-bit signal processing is presented for reduction of the high computational time cost. As for two-dimensional-positioning measurements, a system for supporting such a case has also been presented by using one sound source and two sensors. Although these methods including both one and two dimensional ultrasonic measurements have high resolution, they are designed in very high-cost price of the receivers. It is not convenient for a three-dimensional ultrasonic system because the system requires more than one or two receivers. Instead, to support low-cost applications, a hand held communication

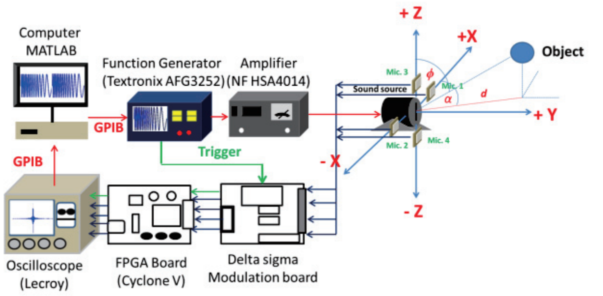


Fig. 1 Three-dimensional-positioning airborne system.

device, which is much cheaper than an acoustical microphone of the previous version, is utilized for the new. An idea for three-dimensional-positioning measurements has been already defined, relied on a numerical method via three microphones [6]. However, this system has restriction of a detection area, which is limited under ninety degrees of positive X, Y, and Z axes. To enhance the area of detecting the object on both positive and negative sides, this paper proposes the new system shown in Fig.1 by performing four hand-held-communication devices as receivers. The object location is observed via the distance ($d$) between the sound source and the object, the angle of elevation ($\phi$), the angle of azimuth ($\alpha$). Additionally, a delta-sigma modulation board and FPGA are adapted to support real-time applications in the proposed system. The validity of the new system is confirmed by repeatability of the experimental results.

## 2. EXPERIMENTAL PROCEDURE

The experimental setup for the ultrasonic three-dimensional-positioning system is proposed in Fig. 1. In the experiment, the frequency of the transmitted LPM signal was swept from 50 $k$Hz down to 20 $k$Hz. The length of the transmitted LPM signal was 3.274 $m$s. A driving voltage of the function generator was 4 $V_{p\text{-}p}$. The LPM signal was distributed from the function generator and enlarged by 10 times with an amplifier. The loudspeaker transmitted the LPM signal, and then the spherical object, having a diameter with 10 cm, was sensed by four hand-held communication devices. Thus,

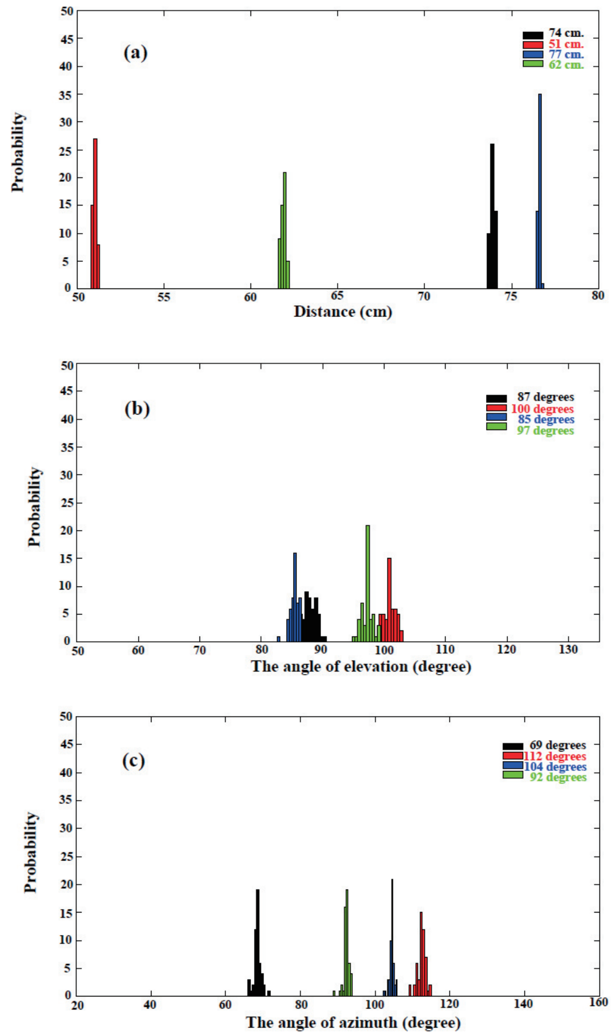


Fig. 2 The probability distributions of the position measurements

the distance from the loudspeaker to the microphones on X axis was 10 cm. On the other hand, that on Z axis was 11 cm. The propagation velocity of an ultrasonic wave in the air was approximately 345 m/s at the temperature 25$^{o}$ C and the humidity 50 R.H. The signals obtained by the acoustical receivers were converted into one-bit signal by 7$^{th}$ –order delta-sigma modulator. The sampling frequency of the delta-sigma modulator was 12.5 MHz. The cross correlation and the smoothing operation by 141 taps of weighted moving average filter was designed and embedded on the FPGA board model cyclone V.

## 3. EXERIMENTAL RESULTS

The three-dimensional-positioning method is proposed by using only the TOFs measurements.

The spherical object was localized in the three dimensions with the various positions. The object position was evaluated repeatedly with 50 times at the same condition. Statistics of measurements was used for evaluation. The direct sound, which sensed by the receivers on Z axis, has smaller amplitude than on X axis. It agrees with the property of the speaker, which tells us that ability of the loudspeaker in X-Y plane has stronger sound intensity than in Z-Y plane. The normalized pressure field of the sound source the main directivity, symmetrical about +Y with 10 degrees in Z -Y plane and with ±40 degrees in X-Y plane. Hence, the object position in the angle of elevation ($\phi$) was assumed between 80 up to 100 degrees, and the angle of azimuth ($\alpha$) was approximately 60 to 120 degrees. The color bars were implemented for the position distributions at various locations.

## 4. SUMMARY

This paper presented a new system based on one-bit signal processing for detecting the position of an object in three-dimensions space. The system composed of one speaker and four sound receivers. The object position was measured by a distance, the angle of elevation, and the angle of azimuth, between the sound source and the object. The system was designed to support real-time and low-cost applications. The experimental results can confirm the validity of the proposed system.

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