3P5-3

Doppler Measurement With Simultaneous Up-chirp and Down-chirp Plane Wave Transmission

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1. Introduction

Doppler measurement using ultrasound is one of the important techniques in medical scene and many methods have been proposed in order to measure velocity and position of a target. Typical methods include the pulse Doppler method [4], the color Doppler method [5] and the single-FM chirp pulse compression method [6]. These methods have some shortcomings, the pulse Doppler method can only detect the average velocity over several repetitions of the transmission, the color Doppler method detect only spatially averaged velocity because of correlation operation and single-FM chirp pulse compression method cannot apply the situation that multiple scatters have different velocity.

To solve these problems, we use dual-chirp method [1] and we propose to transmit it as a plane wave. At first, we get image by using DAS to identify the location of scatters, and then different velocities of multiple scatters can be detected by analyzing the Doppler shift of the echo corresponding to each target in the received signal of each element. By transmitting with plane wave, the received signal of each element is contained Doppler shifts in different directions, so that not only the velocity and position of the target but also its two-dimensional direction can be obtained with only one transmission and reception.

2. Method

2.1 Dual chirp method

In previous study [1], transmit sum of FM up-chirp and FM down-chirp to moving reflector and receive echo signal then compress it with up-chirp and down-chirp, respectively. The compressed waveform has a time shift t_d with respect to the true position and t_d directions of up-chirp and down-chirp are opposite each other. The time shift can be expressed as follows:

$$t_d = \frac{f_d T}{B}. \qquad (1)$$

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provided that f_d indicates the Doppler frequency, T represents the width of the transmitted FM-chirp pulse, and B is frequency bandwidth thereof.

2.2 Principle of the proposed method

We propose transmit Dual chirp as plane wave to measure the Doppler velocity, direction and location of target. At first, Doppler effect model is represented in **Fig. 1(a).** On the basis of Fig. 1(a), our proposed method shown in **Fig. 1(b)** can be written as follows:

$$f_R^N = \left(\frac{f_0 \left(1 + \frac{v \cos\theta_T}{c}\right)}{1 - \left(\frac{v}{c}\right) \cos\theta_R^N} \right) \qquad (2)$$

provided that N indicates number of elements and f_R^N represents each element has different Doppler shift. In other words, we can determine not only the velocity and position of target but also the direction of travel from this equation. This allows the velocity, position and direction can be obtained with only one transmission and reception.

3. Simulation

In this study, the echo signals were calculated using Field II which is a program for simulating ultrasound transducer fields and ultrasound imaging using linear acoustics.

A simulation model is shown in **Fig. 2**. In this system, three scatters placed in the field and each scatter have different velocity $v1 = 8.6\ \mathrm{m/s}, v2 = 10\ \mathrm{m/s}$ and $v3 = 6\ \mathrm{m/s}$. For simulate our method,

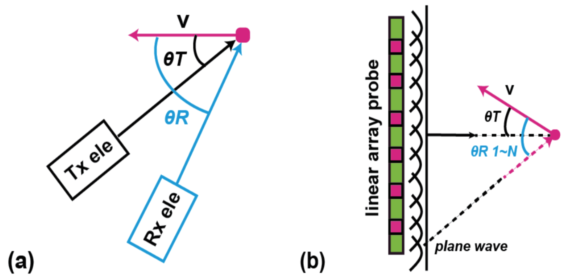

Fig. 1 principle of Doppler effect (a) simple Doppler model (b) proposed method and N represents number of element

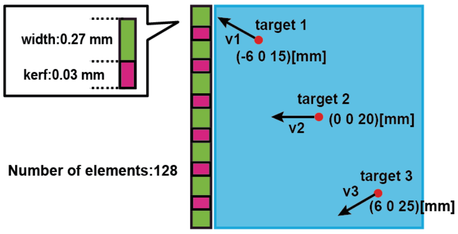

Fig. 2 Simulation Model

we use 128 elements linear array transducer and the frequency of up-chirp set to 2~10 MHz and down-chirp set to 10~2 MHz. The pulse width thereof was 100 μs and the sampling frequency set to 100 MHz.

4. Result and discussion

Figure 3(a) show the compressed waveform of all targets and **Figs. 3(b)** and **(c)** are B-mode image of compressed result of transmitted up-chirp and down-chirp, respectively. **Figure 3(d)** shows

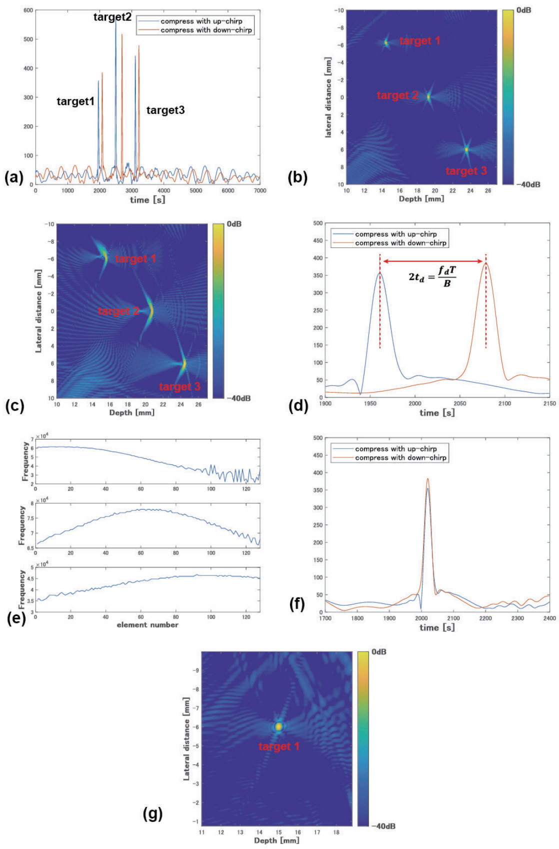

Fig. 3 Simulation results. (a) compressed waveform of up and down chirp, (b) and (c) are DAS images of up and down chirp, (d) time shift of target 1, (e) Doppler frequency of all targets, (f) compressed waveform of target 1 considered Doppler frequency, (g) DAS image of target 1 calculated from (f).

echo of target 1. From B-mode image, we can estimate which target corresponds to which echo, and then Doppler frequency can be calculated from Eq. (1). **Figure 3(e)** is calculated Doppler frequency of all targets. **Figure 3(f)** shows the compressed waveform that considered Doppler frequency both up and down chirp and the compressed waveforms are in the same position. It shows the correct position of the target 1 and B-mode image is shown in **Fig. 3(g)**. The same procedure can be used for other targets to determine the true position.

As can be seen these results, we get true position and Doppler frequency of all targets. Furthermore, speed and direction of target can be calculated from Eq. (2) and Doppler frequency shown in Fig. 3(e). To determine the velocity and direction, we focus on target 2 as an example and obtained results $v_2 = 9.85\ \mathrm{m/s}, \theta_t = 0°$. In this simulation, the measurement error of velocity was $0.15\ \mathrm{m/s}$.

5. Conclusion and future works

In this paper, we proposed the method of transmitting dual-chirp as a plane wave and determine the position, velocity and direction of the scatters. The calculated result show that can measure the velocity of scatters with a small error.

In the future, we will extend this method to the situations where more scatters are in the field or complex environment like living tissue and propose more efficient algorithm to calculate velocity and direction of scatters.

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