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Basic study on correction of speed of sound in forming of non-cylindrical focus beam

非球面フォーカスビーム形成における音速補正に関する基礎検討

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1. Introduction

A plane-wave-based ultrasonic imaging method with a high temporal resolution of up to 10 kHz can visualize the blood flow dynamics in details [1, 2]. In our group, a blood flow imaging method [3] visualizing echo signals from blood cells themselves was developed using the high temporal ultrasonic imaging and singular value decomposition (SVD) filter [4]. However, there is a possibility that the high temporal ultrasonic imaging is susceptible to side and grating lobes because the transmitting wave is not spatially focused.

Although the effects due to both the side and grating lobes can be suppressed using a spatially focused transmitting beam, blood flow imaging using the focused beams and SVD filter needs to be investigated. As a lateral width of the conventional transmitting beam changes along a depth direction, non-cylindrical [5] and hybrid [6, 7] transmission focusing methods are investigated in this paper. These two focusing methods were developed to form ultrasonic beams with the uniform lateral width along the depth direction. However, as heterogeneity of speed of sound (SoS) in a tissue influences forming both the transmitting and receiving beams, proper SoSs need to be used in the beamforming process.

In this study, we aimed to investigate a proper transmission focusing method forming ultrasonic beams with the uniform lateral width along the depth direction using the actual SoSs estimated from coherence factors (CFs) [8]. In this paper, simulation experiments are focused on to investigate the proper number of active transmitting elements and focal depth in transmission using Field II [9, 10].

2. Materials and Methods

2.1 Transmission focusing methods

In this paper, three different transmission focusing methods including the conventional method are evaluated based on a depth of focus (DOF) and a beam width at a peak pressure. Time delays of signals applied to transducer elements in each transmission focusing method are calculated using equations described in following sections.

2.1.1 Conventional focusing method

The delay time applied to an ultrasonic element at a position $(x_i, 0)$ for the conventional transmission focusing method are calculated using the following equation as

$$t_{dc}(x_i, z_f) = \frac{\sqrt{z_f^2 + x_i^2} - z_f}{c}, \qquad (1)$$

where variables z_f and c are a focal depth, and SoS, respectively. In the simulation, the focal depth z_f was changed from a depth of 5 mm to 25 mm with a step of 5 mm.

2.1.2 Non-cylindrical focusing method [5]

When the lateral position x_i is smaller than a value $z_{fmin}x_{ha}/z_f$ (z_{fmin}: minimum focal length, x_{ha}: a half active aperture size), the delay time for the non-cylindrical transmission focusing method are calculated using the following equations as

$$t_{dnc}(x_i, z_f) = \frac{z_f z_{fmin}\left\{\alpha\left(\frac{x_i}{z_{fmin}}\right) - \alpha\left(\frac{x_i}{z_f}\right)\right\}}{c(z_f - z_{fmin})}, \qquad (2)$$

where the function α is expressed as a follow:

$$\alpha(\xi) = \sqrt{1+\xi^2} - ln\left\{1 + \sqrt{1+\xi^2}\right\}. \qquad (3)$$

In this paper, the minimum focal length z_{fmin} was set to be 5 mm. In the other case, the delay time for the non-cylindrical transmission focusing method are calculated using the following equation as

$$t_{dnc}(x_i, z_f) = \frac{z_f x_i\left\{\alpha\left(\frac{x_{ha}}{z_f}\right) - \alpha\left(\frac{x_i}{z_f}\right)\right\}}{c(x_{ha} - x_i)}. \qquad (4)$$

In the simulation, the focal depth z_f was set to be to 25 mm.

2.1.3 Hybrid focusing method [6, 7]

When the lateral position x_i is smaller than a value X_1, the delay time for the hybrid transmission focusing method is equal to that obtained by equation (1). In the other case, the delay time for the

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hybrid transmission focusing method are calculated using the following equations as

$$t_{dh}(x_i,\ z_f) = \frac{1}{c}\left(\frac{Z_2 - Z_1}{x_{ha} - X_1}x_i + Z_1 - \frac{Z_2 - Z_1}{x_{ha} - X_1}X_1\right), \quad (5)$$

where the variable Z_1 is calculated by $ct_{dc}(X_1,\ z_f)$. Also, the variable Z_2 is given by

$$Z_2 = Z_1 + (x_{ha} - X_1)\tan\theta\,. \quad (6)$$

In this paper, the variable X_1 was set to be a quarter active aperture size. The focal depth z_f was changed from a depth of 5 mm to 25 mm with a step of 5 mm. Also, the angle θ of the wave front was changed from 2 degrees to 10 degrees with a step of 2 degrees.

2.2 Simulation experiment [9, 10]

Acoustic fields are simulated using Field II [9, 10] to evaluate the DOF and beam width at the peak pressure. A 7.5 MHz linear array probe with an element pitch of 100 μm was used in this simulation. Also, active aperture sizes of 16, 32, 64, 96, 128 ch were investigated.

3. Results and Discussions

Figure 1 shows the estimated acoustic fields with non-cylindrical transmission focusing method using the active aperture sizes of 16, 32, 64, 96, and 128 ch from left to right, respectively. The DOF and beam width at the peak pressure were calculated from the estimated acoustic fields described above. As shown in Fig. 1, the transmitting ultrasonic beam with the uniform lateral width was achieved using an active aperture size of 64 ch. In this case, the DOF and beam width were calculated to be 26.3 mm and 1.23 mm, respectively. Hence, for the non-cylindrical transmission focusing method, an active element of 64 ch and a focal depth of 25 mm were proper to achieve the desired transmitting beam.

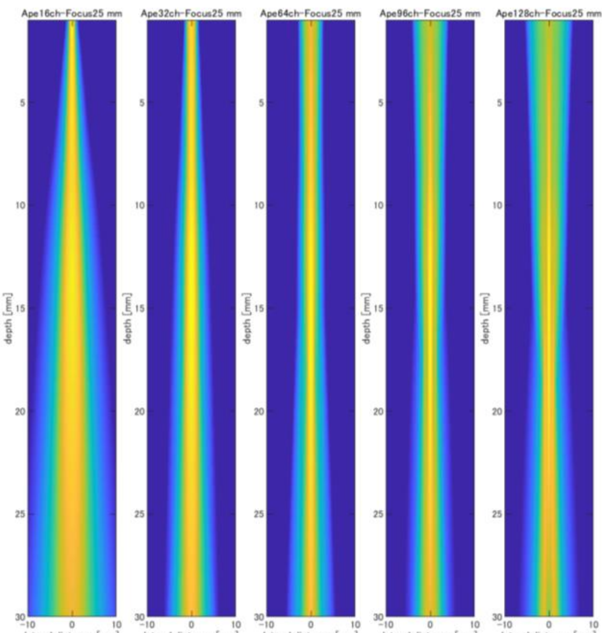

Fig. 1 Acoustic fields with non-cylindrical transmission focusing method using the active aperture sizes of 16, 32, 64, 96, and 128 ch from left to right, respectively.

4. Conclusion

In this paper, the simulation experiments were focused on to investigate the proper number of active transmitting elements and focal depth in transmission using Field II. For the non-cylindrical transmission focusing method, an active element of 64 ch and a focal depth of 25 mm were proper to achieve the desired transmitting beam.

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