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Adaptive Compound of Angle and Frequency with a Single Plane Wave Transmission

1 回の平面波送信による角度と周波数の適応的コンパウンド

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1. Introduction

Imaging using ultrasound is useful method in terms of non-destructive and non-exposure. In the biomedical field, this method is used to detect cancers and observe the fetus. However, due to the variation in the speed of sound inside the human body, ultrasound images are degraded. Our previous study [1] tried to resolve this problem by transmitting plane waves every angle and frequency and compounding all of them with weightings called that FPWC-MVDR (frequency and plane-wave compounding-minimum variance distortionless response). Therefore, this resolving method requires transmitting many plane waves, which costed a lot of time for recording echoes and calculating image.

We propose a new method to realize adaptive compound of both subband and transmission angle in one plane wave transmission. In this method, several different band chirped pulses are transmitted all at once in different directions. However, these subband chirped pulses are defined so that half of their bands overlap each other. As a result, crosstalk occurs between the echoes. Also, unlike FPWC-MVDR, only one subband is transmitted in each transmission direction. The proposed method has a better frame rate than the conventional method, but the above two points may reduce the image quality. In this study, in particular, the proposed method is compared with simple DAS and FPWC-MVDR to evaluate the effects of the above crosstalk.

2. Method

In the proposed method, plane wave pulses of different frequency are transmitted in several angles at the same time. Therefore, received echoes is including different transmission angle and frequencies at the same time. We calculate the adapting B-mode image by the steps following below.

Element a recorded the echo signal of the direction b as x_{ab}. After receiving echoes, an average of all echoes excluding echo of element i defines as y_{ij}, and vector $\boldsymbol{s}_i = [y_{i1}, y_{i2}, \dots, y_{iL}]^H$ is obtained. Dispersion-covariance matrix $\boldsymbol{R}_j$ can be written as follow:

$$\boldsymbol{R}_j = \frac{1}{N}\sum_{i=1}^{N} \boldsymbol{s}_i \boldsymbol{s}_i^{\mathrm{H}} \quad (j = 1, \ \dots, \ N)$$

where $^{\mathrm{H}}$ is Hermitian transposition, N is the number of directions, and L is the number of elements. Optimal wight vector for element j is obtained from

$$\widehat{\boldsymbol{w}_j} = \frac{\boldsymbol{R}_j^{-1}\boldsymbol{1}_L}{\boldsymbol{1}_L^{\mathrm{T}}\boldsymbol{R}_j^{-1}\boldsymbol{1}_L}$$

where $\boldsymbol{1}_L$ is a vector of dimension L and all elements are 1. Then, pixel intensity p can be obtained as

$$p = \sum_{i=1}^{L}\sum_{i=1}^{N} \widehat{\boldsymbol{w}_j}^{H} x_{ij}$$

3. Simulation

The performance of the proposed method was evaluated by the finite element method using the OnScale simulator. In the simulation, we could not transmit all waves at same time, we transmitted each angle separately and summed up all echoes. MATLAB software is used for experimental calculation.

The beamforming procedure was performed offline on the ultrasound echoes received by the individual transducer elements. In this simulation, the sampling frequency is 812.87 MHz and sampling points is 20,320.

We prepared 3 simulation models I) one target in water, II) 5 targets arranging a cross pattern in water, and III) 5 targets arranging a cross pattern in liver as shown at **Fig. 1**. A plane wave was transmitted and the whole array composed of 96 elements received the echo. The element width is 0.04 mm and pitch is 0.03 mm. Targets places in each models are shown in Fig. 1.

For transmission, 14 Chirp pulses are used which the center frequency is changed from 2.5MHz to

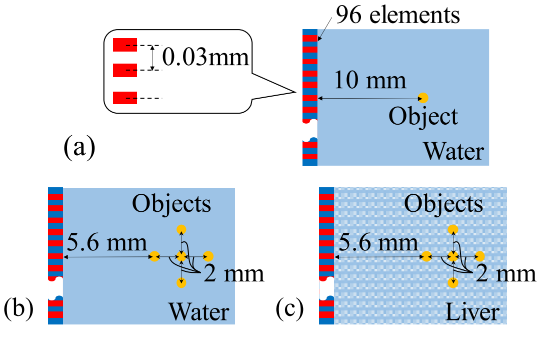


Fig.1 Simulation setups of (a) Model I, (b) ModelII, and (c) ModelIII

deg	-12°	-10°	-8°	-6°	-4°	-2°	0°
setA	2.5	4	4.5	6	6.5	8	8.5
setB	8.5	6	2.5	4	6.5	4.5	5.5
setC	8.5	7	6.5	5	4.5	3	2.5

(MHz)

deg	2°	4°	6°	8°	10°	12°
setA	7.5	7	5.5	5	3.5	3
setB	5	3	7.5	3.5	8	7
setC	3.5	4	5.5	6	7.5	8

(MHz)

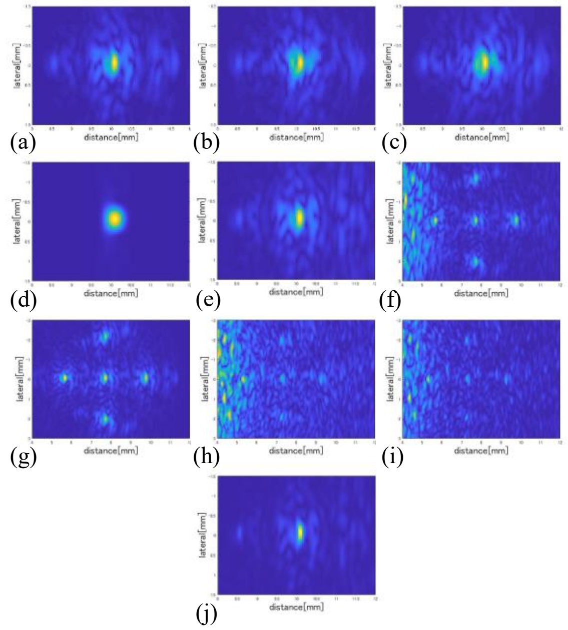
Table.1 Frequency sets

8.5MHz in 0.5MHz increments and bandwidth is 1MHz, and the last one is center frequency is 5.5MHz and bandwidth is 6MHz. For changing center frequencies every direction, we prepare 3 frequency sets as shown at **Table 1**. Set A is a frequency at 0° is maximum and decreasing as angle increases. Set B is a 0° frequency is middle and the others are random. Set C is a 0° frequency is minimum and increasing as angle increases.

4. Result and Discussion

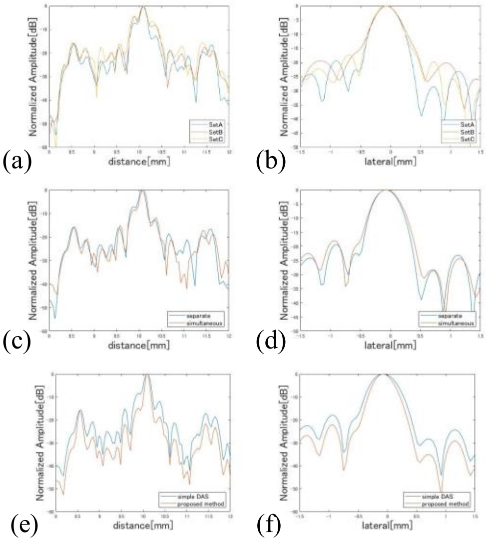
First, we decided which frequency set is the best. **Figs. 2** (a) to (c) illustrates the simple DAS B-mode images of 3 frequency sets and **Figs. 3** (a) and (b) shows their profiles in Model I. For the reference, B-mode image using wide bandwidth pulse shows at (d). Set A is the best. This is why wavelengths extend as frequency is increasing and the wavelengths of distance direction gets similar. From here, we used Set A.

Second, we checked the interference of simultaneous transmission. Fig. 2 (e) illustrates the simple DAS B-mode images of simultaneous transmission in ModelI and Figs. 3 (c) and (d) shows their profiles. There are no remarkable interferences between separate and simultaneous transmission in this region. We think this is a help of frequency assignment. But compared with Fig. 2 (g), a front part of the image is disturbed. This may be occurred by the interference with waves themselves.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)

Fig.2 Simple DAS B-mode images of using frequency set (a) Set A, (b) Set B, (c) Set C, and (d) wide bandwidth pulse; (e) simultaneous transmission using Set A in Model I; (f) in Model II with simultaneous transmission and (g) with separate transmission. (h) Model III. (i) is proposed method in Model III; and (j) is the proposed method in Model I.



(a) (b) (c) (d) (e) (f)

Fig.3 Intensity profiles along (a) distance direction and (b) lateral direction of Fig.2 (a) to (c); (d) is along distance direction and (e) along lateral direction of Fig.2 (a) and (d); (e) (a) distance direction and (b) lateral direction of Fig.2 (e) and (j).

Third, we confirmed the effect of targets location and background. Figs. 2 (f) and (h) shows simple DAS B-mode image in ModelII and ModelIII. There are few effects of target location. But images are affected by background. This is by the wave attenuation.

Lastly, Fig. 2(i) shows the B-mode image by proposed method. It is hard to see the difference between Figs. 2 (h) and (i). But compare Figs. 2 (e) and (j), and Figs. 3 (e) and (f)the effect of this method can be seen.

5. Conclusion and Future Work

We have proposed a new method for enhancing B-mode image with one transmission. In a part of middle and back region, there are no remarkable change between separate and simultaneous transmission. In terms of frequency assignment, we conclude the frequency is decreasing as angle increases is the best.

In the future, we aim to propose a better compound method and reduce the effect from wave interferences on the front part of the region. Moreover, we'll compare this method to FPWC-MVDR.

6. Reference

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