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Ultrasound Imaging with a Single Transmitter/Receiver Circuit Based on Selective Addition of Received Signals

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1. Introduction

In medicine, ultrasound imaging is widely used as a minimally invasive examination method. Generally, an array probe system consisting of multiple transducers is used for imaging. In this system, transducers are arranged in a line, and each transducer is connected to a transmitter/receiver circuit. This requires a large number of transmitter/receiver circuits, making the system complex and expensive.

To achieve low-cost ultrasound imaging, studies[1-3)] have been conducted to reduce the number of receiving elements by using synthetic aperture technique. Since there is redundancy in the received signal of each transducer, ultrasound imaging can be achieved with fewer receiving circuits than the number of elements in the full array by efficiently selecting the receiving elements.

In this study, we propose ultrasound imaging with a single transmitter/receiver circuit based on selective addition of received signals. Using reception redundancy to sparse the elements used for reception reduces the available energy and lowers the SNR. To avoid this, the echoes received by multiple elements are added analogously and captured by the computer, and then the necessary information is extracted by receive beamforming. In this approach, each element is connected to a single transmitter/receiver circuit via switching circuits. In transmission, multiple elements are selected and used simultaneously. At reception, the received signals from the selected multiple elements are connected together to produce a single received signal. This approach achieves low-cost ultrasound imaging using a single transmitter/receiver circuit.

2. Method

In the proposed method, multiple elements are selected from an array transducer and ultrasound waves are transmitted simultaneously by a single transmitter circuit. The transmitted ultrasound waves are reflected by the target and received by the selected elements, and the added echoes of elements are recorded by a single receiving circuit. At this time, the element swich randomly selects different elements in transmission and reception to reduce wave interference. This measurement is performed multiple times with different selection patterns to achieve imaging.

The image for each measurement is generated by the DAS beamformer shown in the following equation.

$$x(t) = \sum_{e}^{E} s(t - \tau_e) \tag{1}$$

where s is an added echo, $e = \{e_1\, e_2 \ldots E\}$ is the combination of transmitting and receiving elements, τ_e is the delay time of transmission and reception between elements, and x is the image.

The images generated by all measurements can be combined to produce a high-quality image. The proposed method aims to improve image quality by weighted addition using coherence factor (CF). The CF weights are defined by the following equation.

$$\boldsymbol{w_{CF}} = \frac{\left|\frac{1}{N}\sum_{n=1}^{N} \boldsymbol{x_n}\right|^2}{\frac{1}{N}\sum_{n=1}^{N} |\boldsymbol{x_n}|^2} = \frac{\left|\sum_{n=1}^{N} \boldsymbol{x_n}\right|^2}{N\sum_{n=1}^{N} |\boldsymbol{x_n}|^2} \tag{2}$$

where $\boldsymbol{x_n}$ is the image generated by each measurement.

3. Simulation

To evaluate the proposed method, simulations were performed using the finite element method. The model of the simulation is shown in **Fig. 1**. An area of 15x10 mm was imaged using a 64-channel transducer array with 0.315 mm element spacing. A transducer with a bandwidth of 81.7 % and a center

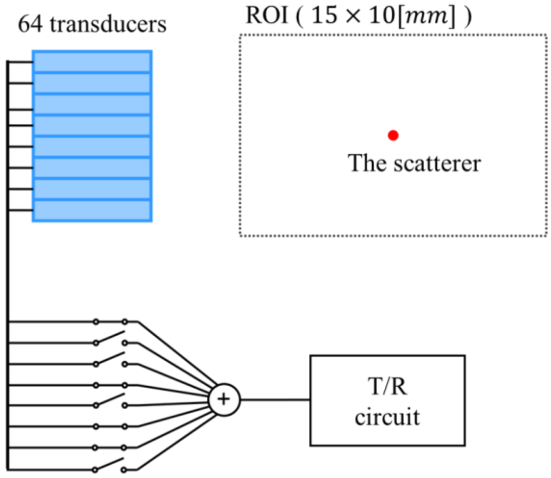

Fig. 1 The model of simulation

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frequency of 7.52 MHz was used to transmit a Gaussian windowed 2.5 cycles sin wave. To generate the images, 16 measurements were taken, and for each measurement, 4 elements were randomly selected for transmission and reception differently.

For comparison, images were generated for the cases where the same elements were used for both transmission and reception, and where multiple circuits were used to receive signals from each element individually.

3. Results and Discussion

Figure 2(a) shows an image of the proposed scheme which different random elements are selected for transmission and reception, and the added echo is received by a single receiving circuit, **Fig. 2(b)** shows an image of the proposed scheme when the same element is used for transmission and reception, and **Fig. 2(c)** shows the images when multiple receiver circuits are used.

From Figs. 2(a) and (b), it can be seen that unwanted interference appears in the background when the same element pattern is used for transmission and reception compared to the proposed method. This is believed to be due to the fact that the same element pattern was used for transmission and reception, and a single circuit was used for reception, resulting in unwanted interference even in areas where there were no targets.

From Figs. 2(a) and (c), the proposed method was able to generate an image with a slightly higher background level but not much lower quality than that generated by using multiple receiver circuits. This is thought to be because the proposed method uses a single receiver circuit to receive the signals that are added, and beamforming cannot completely separate the signals of each element. By using the redundancy of the received signal, imaging could be achieved with a single receiver circuit, therefore reducing the circuit cost.

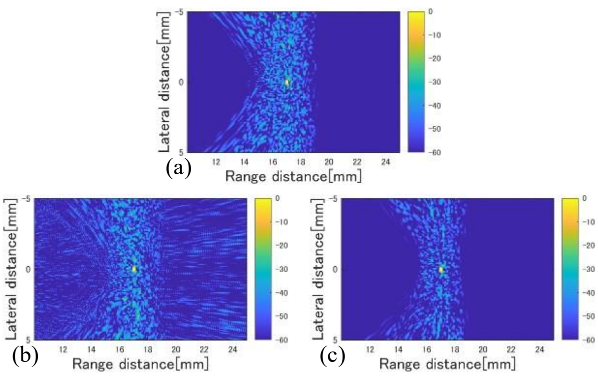

Fig. 2 B-mode images of (a) Proposed method; (b) same electrodes were use for transmission and reception; (c) receive with multiple circuit.

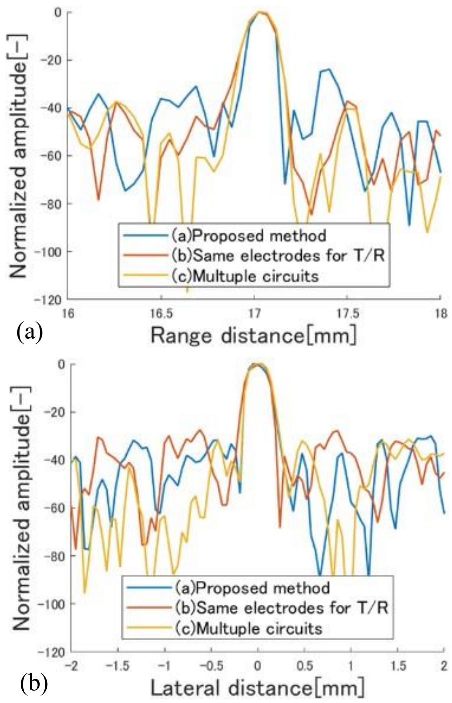

Fig. 3 Amplitude profiles of the images in Fig. 2 along (a) range direction; (b) lateral direction.

Amplitude profiles in the range and lateral directions for each image in Fig. 2 are shown in **Fig. 3**. Figure 3 shows that there is no difference in resolution between any of the methods and that the resolution does not change with the addition of the received signals.

5. Conclusion and Future Work

We have proposed ultrasound imaging using a single transmitter/receiver circuit based on selective addition of received signals, and have confirmed by simulation that it is possible to generate images. By using the redundancy of the received signals, the proposed method can generate images with a single circuit that are not so inferior to the images with multiple circuits.

In the future, we will work on more efficient electrode patterns with less redundancy by considering electrode patterns other than random electrode selection for further improvement of image quality.

References

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