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A Study on Lateral Resolution Improvement of a Wide Pitch Probe by Compressed Sensing

圧縮センシングによるワイドピッチプローブの横方向分解能向上に関する研究

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1. Introduction

Ultrasound imaging systems have become popular in the medical field as a diagnostic method that can be performed easily. However, due to the rigid surface of ultrasound probes, it is difficult to image areas where bones are close to the body surface, such as finger joints and knees.

Flexible probes [1] can be a useful solution to this problem. Since the surface of a flexible probe can be curved, it can adhere to finger joints and knees. However, the pitch of the elements of many flexible probes developed so far is wide, and the lateral resolution is poor compared to that of ordinary probes.

Compressive sensing [2-4] is one of the effective methods to solve this lateral resolution problem. Compressed sensing utilizes the sparsity of data to recover the target signal from a small number of data. By applying this method, data completion between elements of a probe with a wide pitch is attempted.

2. Method

2.1 Compressive sensing

Signal acquisition in compressive sensing can be represented as

$$y = \Phi x \quad (1)$$

where x is the received signal, Φ is the sampling scheme, and y is the observed signal. Compressive sensing uses the sparsity of the solution to estimate the solution. Therefore, assuming that the received signal is sparse, we can write

$$x = \Psi u \quad (2)$$

where ψ is the sparse transformation matrix and u is the sparse transformation coefficient. By substituting Eq. (2) into Eq. (1), we obtain

$$y = Au \quad (3)$$

where $A = \Phi\psi$ is the measurement matrix. Equation (3) can be solved using the optimization algorithm by posing a recovery problem:

$$\min\|u\|_1 \quad \text{subject to} \quad Au = y \quad (4)$$

Now, Eq. (4) can be solved using the basis pursuit. Once u is recovered from Eq. (4), x is obtained using Eq. (2).

2.2 Simulation

In this paper, the ultrasonic numerical simulation software Field-II is used [5]. Two probes, one with 64 elements and the other with 32 elements, are modeled and the proposed method is implemented with the 32-channel probe.

The results obtained from the probe with 64 elements are used for comparison.

The target is a single point scattering phantom placed at a depth of 15 mm. The parameters of the simulation are shown in **Table 1**. The data obtained by the 32-element probe was complemented by applying compressed sensing to produce a low-resolution image with 64 elements of data, as shown in **Figure 1**. In this case, the apertures of the two probes are the same. The aperture synthesis was calculated using the Beamformation toolbox of Nikolov et al[6]. The ultrasonic signal was transmitted by one element and received by all elements. This operation is repeated while shifting one element at a time.

In the proposed method, we assume that the low-resolution image of the 32-element probe is similar to the low-resolution image of the 64-element probe with 32 elements removed at even intervals. This was done for all 32 low-resolution images. In this process, compressed sensing was calculated using SPGL1 [7]. The images were then imaged and compared with the 64-element probe.

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Table 1: Parameters of probes

Parameters	Values	
	64-channel	32-channel
Number of elements	64	32
Number of transmissions	1	1
Number of receive element	64	32
Pitch [mm]	0.1925	0.385
Center frequency [MHz]	4	4
Sampling frequency [MHz]	100	100
Speed of sound [m/s]	1540	1540

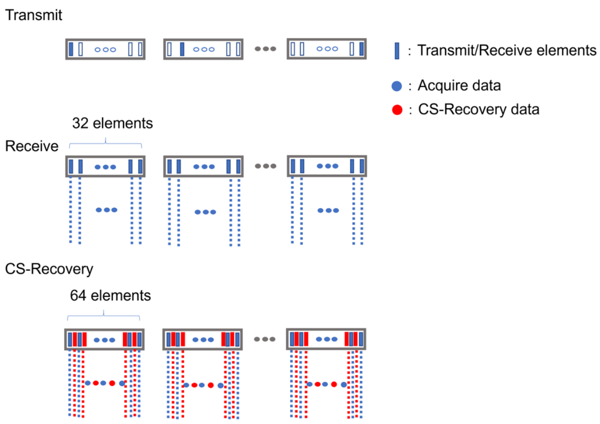

Fig. 1. Schematic of the proposed method

3. Results

Figure 2 shows (a) 64 channel probe, (b) 32 channel probe, and (c) proposed method. **Figure 3** shows 2D-Normalized Beampattern. From Figs. 2 and 3, we can see that the noise is larger in the proposed method.

4. Discussion

In this paper, compressed sensing, which is used in many papers to reduce the sampling rate and frame rate, was used to try to supplement the lack of data caused by the reduction in the number of sensors. As a result, the proposed method reconstructed the noise in the low-resolution image, which resulted in a low horizontal resolution. This result shows that in order to use compressed sensing for data completion, it is necessary to add correction to the original data.

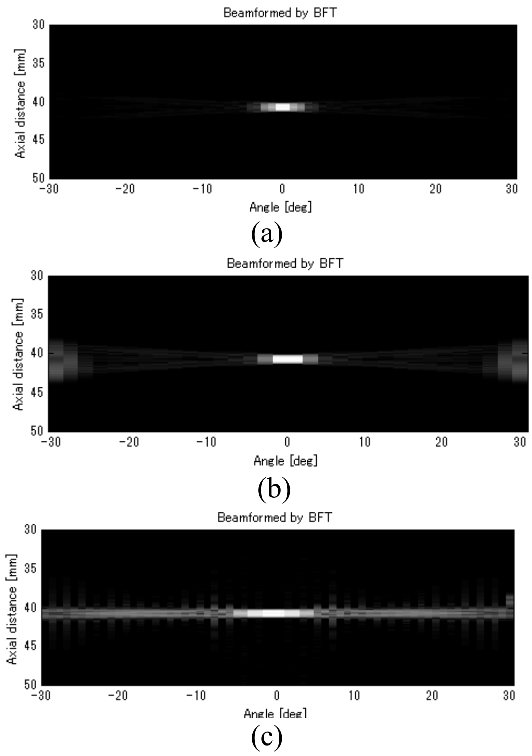

Fig. 2. B-mode image obtained by (a) 64-channel probe, (b) 32-channel probe, and (c) 32 channel probe with proposed method.

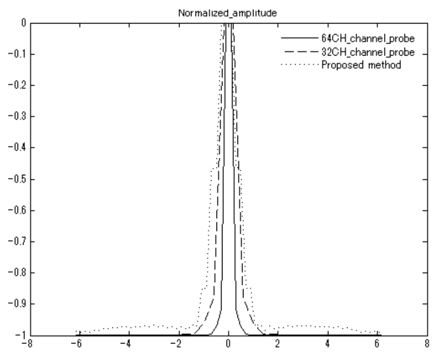

Fig. 3. 2D-Normalized Beampattern.

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