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Super-resolution ultrasound imaging with a single coding mask transducer

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1. Introduction

Recently, ultrasound imaging application in clinical diagnosis has been growing owing to its advantages such as free radiation, low cost, and non-invasive features. The image should have a better resolution and high signal to noise ratio (SNR) for obtaining an accurate diagnosis.

Currently, ultrasound imaging has been conducted by employing a number of elements that are connected with a complex electricity wiring system. To generate the image with a such system, a famous beamforming technique is applied to it. Many researchers have developed methods for improving image quality based on sensor array systems. [1,2)]

However, in some applications in the medical field, systems with features involving a small size device and simple system are required for a specific treatment. For this reason, it is necessary to develop a system with a compact and simple structure. Recently, structured ultrasound microscopy (SUM) was studied by employing single element with attaching irregular acoustic lens to create a spatial coding condition.[3)] However, studying about the method for improving image resolution of such system is still not explored widely.

In a previous study, we proposed Super-resolution correlation method (SCM) with FM-chirp based on MUltiple SIgnal Clasification (MUSIC) for a high ultrasound imaging.[4)] The method was also treated to a single element system by assigning SCM as a weight of image pixels to enhance the resolution.[5)] Refer to this methodology, we propose compression process before computing SCM to obtain better image resolution.

2. Methods

2.1 Image model

In this study the measured RF signals were converted in-phase quadrature (IQ) form in for selecting a real component of complex numbers for processing the image. The image model is defined by following equation,

$$y = \mathrm{D}x, \qquad (1)$$

where y is a set of echo signal, D represents a grid acoustic pressure (in x- and y-axis) of region of interest (ROI). The target image x is computed by solving the numerical linear equation of the model.

In this study, to improve the image resolution, matrix-D was compressed. Each side of Eq. (1) was multiplied by $\mathrm{D^H}$ resulting,

$$\mathrm{D^H}y = \mathrm{D^H D}x. \qquad (2)$$

where H is Hermitian transpose operator.

2.2 Super-resolution correlation method (SCM)

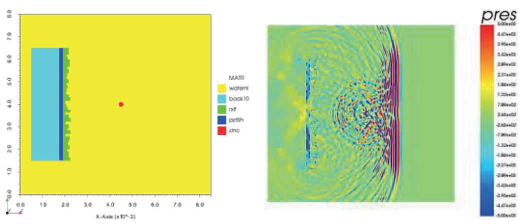
In a previous study, SCM was applied to sensor array system with beamforming method. To improve the image resolution of single element with coding mask system, SCM also possible to be applied on it. SCM is defined by following equation,

$$SCM(\tau) = \frac{r(\tau)^{\mathrm{H}} R_0 r(\tau)}{\sum_{i=Dn+1}^{M} \left|r(\tau)^{\mathrm{H}} e_i\right|^2}. \qquad (3)$$

where $r(\tau)$ is steering vectors represented by each column of matrix-D, R_0 is identity matrix, and e is eigen vector computed from a covariance matrix. In this study, the SCM has assigned as pixel weight for constructing the target image with single scatterer (Dn=1).

3. Simulation

The model was developed by a finite element method (FEM) for ultrasound wave propagation simulator. The proposed model is depicted in **Fig. 1(a)** consisting of backing and a piezoelectric transducer (PZT) element with a coding mask attached to it. The coding mask with a randomized thickness between 0.25λ to 1.0λ, creates a local delay of each patch to scramble a short-pulse transmission wave propagation with frequency of 7MHz. **Figure 1(b)** shows the snapshot of simulation model by a finite element method (FEM). Detail of parameters used in the simulation is shown in **Table 1**.



(a) (b)

Fig. 1. (a) proposed model; (b) Snapshot of simulation of a single transducer covered by a coding mask.

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Table 1. Physical parameters that used in the model simulation

Parameter	Value
Short pulse transmission voltage	50V
Mask (plastic type) sound speed	2,340m/s
Number of mask patch	37
Randomized mask thickness	0.25λ-1.0λ
Backing thickness	1.25mm
PZT thickness	0.12645mm
Center of frequency	7MHz
Distance of PZT to target position	±2.5mm
Radius of target	0.1mm

For constructing the image, the set of echo signals from the scatterer positioned in ROI was measured. For collecting the D-matrix, the acoustic pressure was measured in ROI without placing any scatterer. The measurement was conducted for 25-angles of rotation to have a better image resolution and computation purpose. The numerical computation for constructing the B-modes was performed by MATLAB R2022a.

4. Results and discussion

The images was constructed by solving Eq. (1) above numerically using I-Q echo signals. **Figure 2(a)** shows a original B-mode image by simple averaging over number of rotation. To improve the resolution, a computed SCM using Eq. (3) was assigned as a pixel weight and was

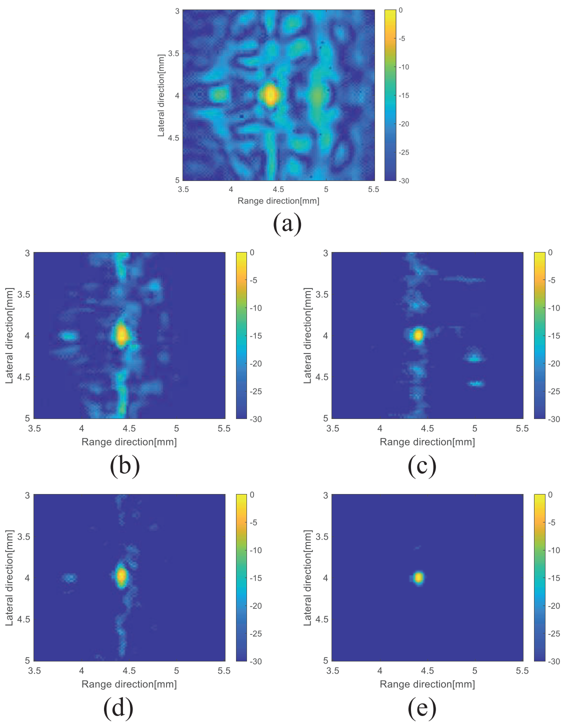

Fig. 2. B-mode images by; (a) simple averaging; SCM with (b) no-compression and (c) compression; CF compounding with (d) no-compression and (e) compression.

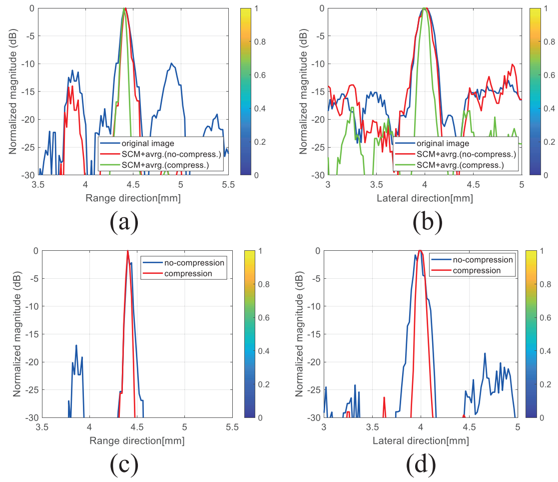

Fig. 3. Amplitude profile with simple averaging in (a) range direction and (b) lateral direction; with CF compound in (c) range direction and (d) lateral direction.

multiplied with previous result. The B-mode image with SCM shows better resolution and better unwanted signal (bakground) suppression (see **Fig.2(b)**). In this study, we performed compression to matrix-D as written in Eq. (2) above. **Figure 2(c)** shows the B-mode image with compressing shows better resolution compared to other images. By using a coherence factor (CF) for reducing the background noise, it also shows the same phenomenan as before as depicted in **Fig. 2(d)** and **2(e)**. To confirm our statement, the amplitude profile of obtained B-mode images in range and lateral directions is shown in **Fig. 3**.

5. Conclusion and future works

We have proposed a new method for enhancing B-mode image of single element with coding mask. The compression process and SCM has significantly improved the image resolution in range and lateral direction. In the future, the experimental stage will be carried out for proving the current simulation results. Along with it, we will also enhance the resolution in lateral direction by studying a proper method for better image quality.

References

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