2E3-2

Realization of 3D Imaging with a Single Element with an Irregular Aberration Lens

不規則収差を有するレンズと単一振動子による３次元画像化の検討

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1. Introduction

To avoid biopsies that require removal of lesions, we are studying puncture ultrasound microscopy that measures acoustic images in vivo. For this purpose, it is necessary to develop an ultrasonic transmission / reception system that is compact and has a simple structure, and a high-resolution imaging method based on the system.

Recently, structured ultrasound microscopy (SUM) has been proposed in which an acoustic lens having random and fine irregularities is attached to the surface of the transmission / reception side on a single oscillator [1][2] (see **Fig. 1**). Spatial coding is realized by the attached acoustic lens giving irregular aberrations to the transmitted and received wavefront. Unlike a typical array transducer, a 3D image of the ROI can be obtained from a single time-series echo signal, simplifying the required electrical circuitry. However, in order to obtain an image having the same resolution as the pathological diagnosis image, various measures are required. One technique for that purpose is to change the spatial coding of the transmitted wave in various ways, measure a plurality of echoes, and use them for imaging. The simplest method is to replace the acoustic lens and perform transmission and reception multiple times, but for efficient and stable measurement, a method of dynamically changing the transmitted wave is suitable.

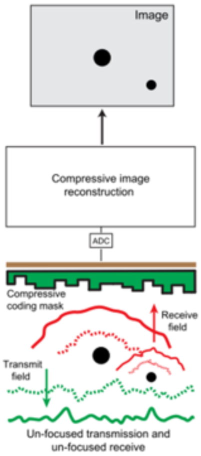

Fig.1 SUM configuration [1].

In this study, as an application of the stochastic resonance phenomenon [3][4], we are investigating a measurement method that irregularly changes the position and transmission frequency of the oscillator. In this paper, as a basic study, the degree of fluctuation of the echo signal received in this way is confirmed by the finite element method simulation.

2. Method

When the measured time-series echo data is $\mathbf{y} = [y_1, y_2, \cdots, y_N]^t$ and the discretized reflectance distribution in the ROI is represented by $\mathbf{x} = [x_1, x_2, \cdots, x_M]^t$ as a one-dimensional vector, the following measurement model can be considered.

$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{n}, \qquad (1)$$

where the $N \times M$ matrix **C** consists of transmission signal information and is sometimes called a dictionary matrix or a design matrix. The N-dimensional vector **n** is the observed noise. Given the observation **y**, restoring **x** is the problem to be solved. As **C** is known, the problem of finding the vector **x** where many components are 0 is generally called compressed sensing. On the other hand, the problem of finding **C** and **x** at the same time with **x** as a sparse vector is often called sparse modeling. In compressed sensing, the solution x is calculated each time y is obtained.

In this study, it is first necessary to find the matrix **C** determined for the measurement system. That is, it deals with sparse modeling. In sparse modeling, the problem is to find **C** for many sets of **y** and **x**, where x is unknown. In the framework of this research, it is required to measure **y** for various imaging objects and determine a common **C** for them. At this time, if an appropriate sparse model is not established, subsequent restoration of x cannot be performed sufficiently. Specifically, it is desirable that the column vector groups constituting **C** have high linear independence.

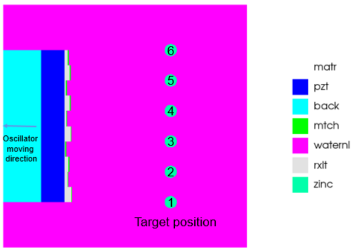

Fig. 2 Simulation model.

The simulation model was shown in **Fig. 2**. We measured the echo signal for each target postion labeled 1-6.

Furthermore, we plan to measure with different matrices **C** by moving the oscillator position back and forth and changing the transmission frequency band. In the learning phase, we determine multiple matrices $\{\mathbf{C}_1, \mathbf{C}_2, \cdots, \mathbf{C}_L\}$. In the inference phase, the unknown **x**, or 3D image, common to the observation groups $\{\mathbf{y}_1, \mathbf{y}_2, \cdots, \mathbf{y}_L\}$, each corresponding to each $\mathbf{C}_i$ $(i = 1, 2, \cdots, L)$ is restored. The higher the independence of $\mathbf{C}_i$, the higher the resolution of **x** can be restored.

In this system, the discrimination of reflections in the depth direction is performed by the time delay of the echo. On the other hand, the lateral discrimination of the same depth will be based on the difference in the transmitted and received waveforms, that is, the difference in the corresponding column vectors of the matrix **C**.

Therefore, at several different depths, the correlation coefficient of the similarity of the echoes from the laterally displaced points was evaluated with reference to the echoes from the central position. The echoes are treated as IQ (In-phase / Quadrature-phase) signals. Assuming that the two IQ signal vectors are **p** and **q**, the similarity $S(\mathbf{p}, \mathbf{q})$ can be defined by the following equation.

$$S(\mathbf{p}, \mathbf{q}) \equiv \frac{\mathbf{p}^H \mathbf{q}}{\sqrt{\mathbf{p}^H \mathbf{p}}\sqrt{\mathbf{q}^H \mathbf{q}}}. \qquad (2)$$

A comparison was made between the fine and rough random patterns of the acoustic lens. Further, based on the above results, changes in echo similarity were similarly evaluated when the position of the oscillator was changed back and forth and when the transmission frequency was changed.

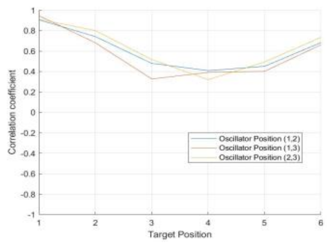

Fig. 3 Correlation coefficien of echo signals each target position with changing the oscillator position.

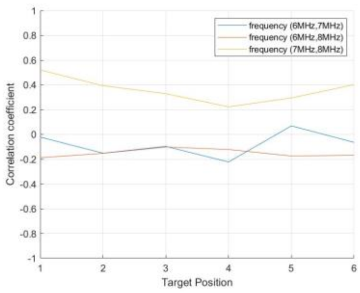

Fig. 4 Correlation coefficien of echo signals each target position with changing the transmitted signal frequency.

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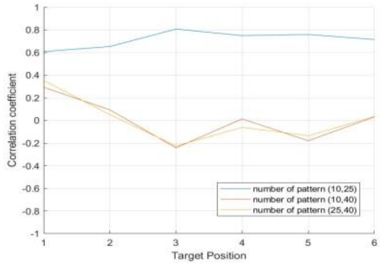

Fig. 5 Correlation coefficien of echo signals each target position with changing number of the random pattern of mask.

3. Results and Discussions

The correlation coefficients of echo signal are graphed in **Fig. 3**, **Fig. 4**, and **Fig. 5**. Moving the oscillator in back-forth with three positions shows the same trend of correlation cofficient. The model also shows the effect of varying the transmitted frequency to the echo signal. The changing correlation coefficient by increasing the number of pattern of mask decreases the simillary of the echo signals.

4. Conclusion and Future Work

In this paper, we reported the SUM model with irregular thickness mask placed in front of oscillator. The echo signals were collected with some mesurement mechanism. In the future, the model will be extended to 3D dimension for constructing a 3D image. The fine and rough irregular pattern mask shows more different echo signals.

5. References

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