Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 511-512
3-5 December, 2014

A Study for High-Definition Ultrasound Imaging Based on Synthetic Aperture Scheme
合成開口方式を基礎とする超音波高精細画像化手法の検討

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1. Introduction

In order to perform high resolution and high signal-to-noise raito (SNR) ultrasound imaging, we have proposed a method for speckle reduction based on the stochastic resonance phenomena [1], a super resolution FM-Chirp correlation method (SCM) [2] and a method for reduction of frequency dependent attenuation (FDA) [3] so far. However, in these methods multiple transmissions of a ultrasound pulse are required for generating each image line. This increases the amount of processing and puts a strict limit on the frame rate. In this study, we attempt to solve these problems through application of a synthetic aperture imaging. As an example, we introduce the synthetic aperture version of SCM and confirm the effectiveness of it throughout simulations.

2. Method

2.1 Synthetic aperture imaging method

The synthetic aperture techniques in ultrasound imaging transmit ultrasonic waves towards a wide range region from a transmitting element as shown in the left part of **Fig. 1(a)**, and the echo reflected from an object P is received by each element for imaging as shown in the right part of Fig. 1(a). Focusing is done as a delay–and-sum beamforming using the distance from a transmitting element to an imaging point and back to a receiving element. Dividing this distance by the speed of sound c gives the time t_k to take out the proper signal. For an imaging point P(x,y) shown in Fig. 1(a) the time is

$$t_k = \frac{\sqrt{(x_i - x)^2 + (y_0 - y)^2} + \sqrt{(x_j - x)^2 + (y_0 - y)^2}}{c}, \quad (1)$$

where (x_i, y_0), denotes the position of the transmitting element i, and (x_j, y_0) indicates the position of the receiving element j. This is done for every point and it can be used to make a low-resolution image just in one transmitting. Moving the transmitting position as shown in **Fig. 1(b)** and combining low-resolution images, which were made in each transmitting can generate a higher resolution image.

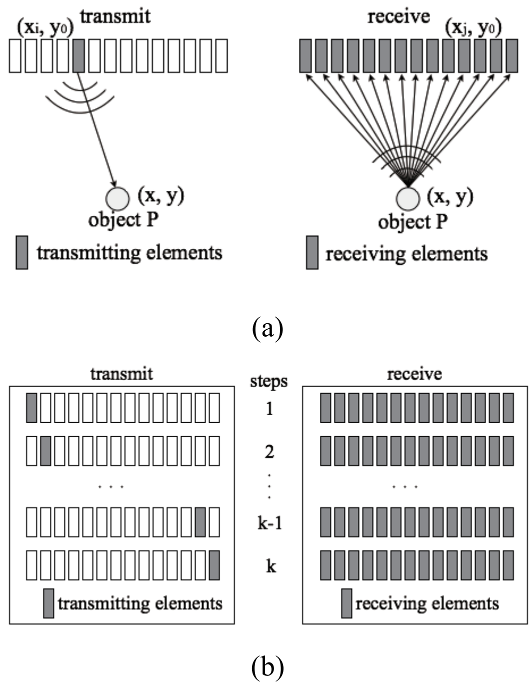

Fig. 1 Schematic of synthetic aperture imaging: (a) the state of transmitting and receiving element. (b) the state of each steps.

By combining several elements for transmission can increase the emitted power and solve the problem of the limited penetration depth which is caused by the transmission of an un-focused wave [4, 5].

2.2 Outline of SCM

SCM is based on the multiple signal classification (MUSIC). It can achieve super-resolution imaging by utilizing the phase information of the carrier waves after compressing FM chirp echo signals. We obtain an analytic signal z consisting of an in-phase component and a quadrature component from a received echo signal to calculate the covariance matrix R=E{zz^H}. From the eigenvalue equation

$$Re_i = \lambda_i e_i \quad : i = 1,2,..., M, \quad (2)$$

we can obtain the eigenvalues λ_i and eigenvectors e_i

(i=1,2,…, M), where M indicates the temporal sampling number of the echo. When we arrange the M eigenvalues in descending order, the first D eigenvalues are large and the eigenvectors corresponding to $\{e_i\}_{i=1}^{D}$ span the signal subspace. On the other hand, a set of M-D eigenvalues λ_i (i = D+1,…,M) gets much smaller than those of $\{e_i\}_{i=1}^{D}$. The eigenvectors $\{e_i\}_{i=D+1}^{M}$ span the noise subspace. In order to estimate the delay of the target's reflection, we use a measure of the orthogonality of the steering vectors to $\{e_i\}_{i=D+1}^{M}$. Accordingly, a super-resolution delay profile $S(\tau)$ based on the MUSIC algorithm can be defined as

$$S(\tau) = \frac{u(\tau)^H u(\tau)}{\sum_{i=D+1}^{M} \left| u(\tau)^H e_i \right|^2}, \tag{3}$$

where $u(\tau)$ denotes the delay profile vector for each delay τ.

The number D should correspond to the number of targets in the echo, and in actual applications of the SCM, for example, the minimum description length (MDL) criterion is used for estimation of D. The accurate second-moment estimate of the delay profile vector has been achieved by repeating the transmission to obtain N snapshots $\{z(j)\}_{i=1,\ldots,N}$. Under these conditions, the covariance matrix can be estimated as

$$\hat{R} = \frac{1}{N} \sum_{j=1}^{N} z(j) z(j)^H. \tag{4}$$

3. Simulations

We confirmed the effectiveness of the proposed method through simulations using PZFlex, which is a standard finite element method (FEM) simulator for ultrasound propagation. **Figure 2** is the model used in the simulations. In this study, we use a short pulse instead of a chirp long pulse. A transmitted pulse which is emitted towards a wide range region is formed by a linear array transducer model with 8 elements and receiving with 64 elements, which is put at the left end of Fig. 2. A transmitted signal to be used as a reference is shown in Table I. Each element width and each separation is 0.08 mm and 0.06 mm respectively, and an aperture with a width of 8.9 mm is formed. A target object is located 10 mm away from the transducer in the area filled with water. We changed the carrier wave's frequency of the transmitted signal for obtaining N snapshots randomly in this simulation to verify the effectiveness of SCM using the synthetic aperture technique.

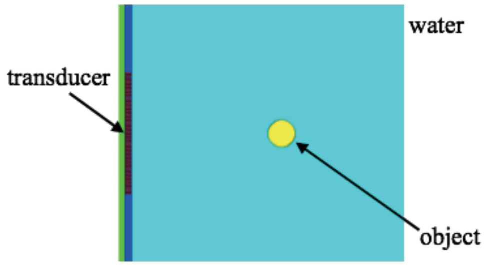

Fig. 2 Simulation model

Table I. Reference signal for transmission

Frequency of transmitted signal [MHz]	5
Cycles of transmitted signal	3
Window function of transmitted signal	Hanning
Focus of transmitted signal	None

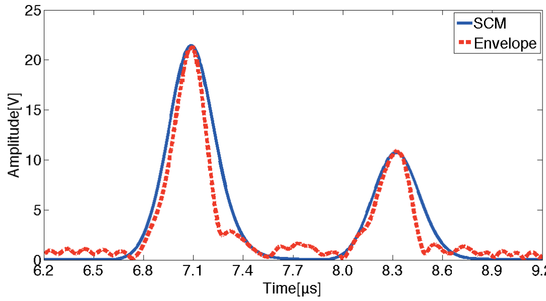

Fig.3 simulation results

4. Results and Discussion

Figure 3 shows the result of SCM using the synthetic aperture. A solid line is the result of SCM and a dotted line is the envelope of the echo signal. Side lobes were reduced but failed to narrow the width of the main lobe in the parameters used in this study. We need to consider for the further research of SCM expanded to the synthetic aperture imaging.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 25350569.

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