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Super-Resolution Ultrasonic Imaging Based on MUSIC Processing in Both of Transducer Element Domain and Beamforming Domain

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1. Introduction

We proposed super-resolution imaging called SCM (Super-resolution FM-chirp Correlation Method) [1], in which the MUSIC (MUltiple SIgnal Classication) algorithm is applied in time direction to echoes received while varying the frequency of the transmision pulse in order to reduce the coherence of multiple targets' echoes. Furthermore, its extension called SA-SCM (Synthetic Aperture-SCM) was proposed [2], in which divergent pulses are transmitted instead of focusing pulses used in the original SCM, and the SCM is applied to the reception beamformed echoes. In the SA-SCM, the number of transmission/reception is reduced. Our recent version is called the SCM-weighted SA [3] in which the SCM is performed on each echo received by each transducer element, and the result is used as the weight for delay-and-sum (DAS) beamforming. It can generate multiple B-mode images corresponding to each carrier frequency, and the appropriate low frequency images among them have no grating lobes. On the other hand, to improve the SNR, simply averaging them is disadvantageous for suppression of grating lobes.

In order to combine these multiple images, the SCM can be applied again to the result of the SCM-weighted SA for all frequencies, which is called the SCM-weighted SA-SCM. Dual application of the SCM can suppress grating lobes, and additionally, it can perform further super-resolution and noise reduction.

2. Method

In this study, the MUSIC algorithm is adopted in signal processing. In order to distinguish the scatterer reflection at different times in the echo with the resolution corresponding to the wavelength of the carrier wave, the use of the phase calculated from the I (in-phase) component and the Q (quadrature) component, which is the analytic signal representation of the echo, can be considered. We can use the analytic signal z to estimate the variance covariance matrix R=E$\{zz^H\}$. From the eigenvalue equation, which is defined as:

$$Re_i = \lambda_i R_0 e_i \ : \quad i = 1,2,\dots,M \tag{1}$$

the eigenvalues $\{\lambda_i\}$ and the corresponding eigenvectors $\{e_i\}$ are calculated, where M indicates the temporal sampling number, and R_0 is a Hermitian matrix corresponding to the variance covariance matrix of the compressed noise component.

To estimate R by which different, we define the following estimate using the analytic echo set $\{z(j)\}$, in which each $z(j)$ is measured by transmitting the pulse having different carrier frequencies.

$$\hat{R} = \frac{1}{N}\sum_{j=1}^{N} z(j)z(j)^H . \tag{2}$$

After arrange the M eigenvalues in a descending order, the first D eigenvalues are much bigger than σ^2, which is the variance of noise component, and those eigenvectors span the signal subspace. While the rest minimal eigenvalues of M-D are almost equal to σ^2 and those eigenvectors corresponding to the noise subspace.

Finally, a super-resolution delay profile $S(\tau)$ based on the MUSIC algorithm can be expressed 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. In actual applications, D should be the number of scatterers, and it can be determined using Akaike's Information Criteria (AIC) or the Minimum Description Length (MDL).

The original SCM uses focused pulse transmission and the MUSIC algorithm to get the result. While the SA-SCM uses divergent pulse transmission and performs the SCM processing for each imaging line. For the SCM-weighted SA, the SCM processing is performed for echoes received by each element, and the results are used as a weight for the DAS beamforming. By the SCM-weighted SA, multiple images each of which corresponds to each carrier frequency. In the new method called the SCM-weighted SA-SCM, the SCM processing is applied again to the results of the SCM-weighted SA in order to integrate them.

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3. Experiment

In the experiment, transmission and reception sequences were generated using RSY0003 (Microsonic Co., Ltd., Japan), a medical ultrasound experiment platform with a sampling frequency of 31.25 MHz. A linear array ultrasonic probe at a nominal center frequency of 7.5 MHz (T0-1599, NIHON DEMPA KOGYO Co., Ltd., Japan) was used. The signal processing was performed using MATLAB software.

Fig. 1 shows the experimental set-up. A vinyl coating metal wire with a diameter of 1.5 mm was placed in the water at a distance of 10 mm from the transducer and was used as an imaging target. In this study, a transmitted pulse is emitted towards a wide range region, which is formed by the center 8 elements, the element pitch of the array is 0.315 mm, while the echo is received by all 64 elements. In the scanning process, 15 pulses with randomly varying the center frequency from 4MHz to 10MHz were performed.

4. Results and Discussions

Fig. 2 illustrates the B-mode images of the averaged SA, the SA-SCM, the averaged SCM-weighted SA and the SCM-weighted SA-SCM, respectively. It should be noted that those averaged results were generated using the 15 RF images corresponding to different transmission frequencies. Compared with the averaged SA, it is confirmed that fine B-mode images have been obtained by all the proposed methods. However, there are still some artifacts arising in the SA-SCM and averaged SCM-weighted SA due to grating lobes. While, it can be seen that the SCM-weighted SA-SCM has a sufficiently super spatial resolution as compared with the other two proposed methods mentioned above.

In order to quantitatively examine the resolution, **Fig. 3** shows a cross-sectional view in the range direction and the lateral direction near the target.

From Fig. 3, it can be confirmed that the resolution of the SCM-weighted SA-SCM is very high in both the range direction and the lateral direction than the others.

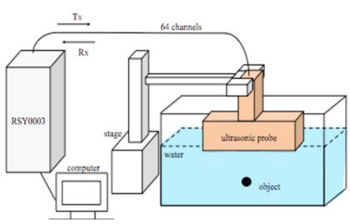
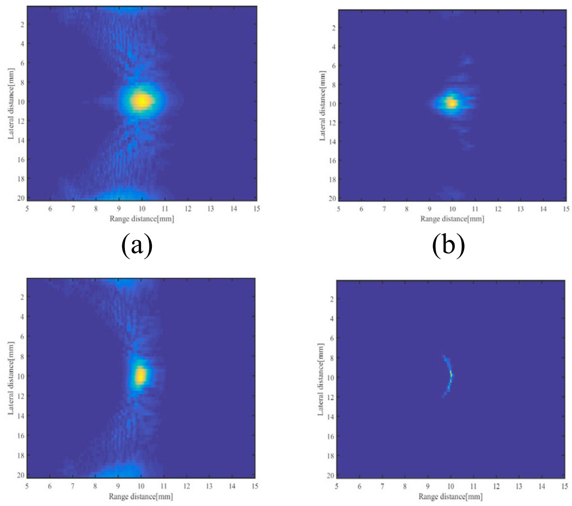
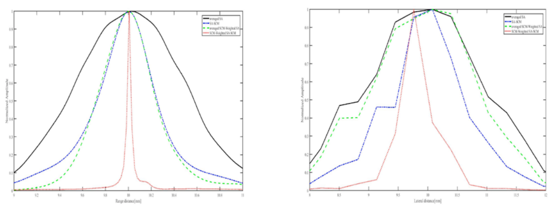


Fig. 1. Experimental setup.



(a) (b) (c) (d)

Fig. 2. B-mode images of experiment results: (a) averaged SA; (b) SA-SCM; (c) averaged SCM-weighted SA; (d) SCM-weighted SA-SCM.



(a) (b)

Fig. 3. Comparison of normalized cross-sectional profile: (a) range profile; (b) lateral profile.

5. Conclusion and Future Work

In this study, dual application of the SCM (SCM-weighted SA-SCM) based on transducer element domain and beamformed line domain for ultrasound images is investigated. Through experiments, it is confirmed that the spatial resolution is improved by the SCM-weighted SA-SCM. In fact, we have confirmed the improvement of spatial resolution by simple experiment. Further consideration of a more specific subject, for example, phantom or living body is ongoing.

References

1. M. Fujiwara: IEEE Int. Ultrasonics Symp. (2009) p.2390.
2. T. wada: Physics Procedia. **70** (2015) 1216.
3. N. Tagawa: Proc Int Conf Pattern Recognition. (2018).