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A Study on Improvement of Lateral Resolution in Ultrasound Super Resolution Method Based on Phase of Carrier Wave

搬送波位相情報に基づく超音波超解像手法におけるラテラル方向分解能向上に関する検討

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1. Introduction

We proposed a method called the SCM (Super-resolution FM-Chirp correlation Method) [1] and the SA-SCM (Synthetic Aperture-SCM) [2]. They realize super resolution in the range direction by using the phase information of the carrier wave by transmitting and receiving a plurality of pulses with different carrier frequencies. The SCM utilizes focused pulse transmission and the SA-SCM is an extension of the SCM to utilized divergent pulse transmission for the purpose of improving the frame rate. The SA-SCM transmits a divergent pulse and applies SA processing [3], for example the DAS (Delay and Sum) [4], as a reception beamforming method to echoes received by all transducer elements. After calculating each line signal, resolution is improved by the SCM. However, since the SA-SCM performs processing for each image line, the resolution in the range direction is improved, but the lateral resolution is not improved. Therefore, in this study, we aim to improve the lateral resolution by using the F-DMAS (Filtered-Delay Multiply and Sum) [5], which is a beamforming method that does not require complicated calculations and can realize high resolution and contrast.

In the SA-SCM, after performing the DAS processing on the RF echo signal, the resulted RF line signal was converted to an analytic signal composed of I (in-pahse) component and Q (quadrature-phase) component, and the SCM was applied. In this study, in order to unify the processing on the analytic signal, the received echo is first converted to the I-Q signal, then the F-DMAS processing is performed and the resulted I-Q line signal is processed by the SCM.

2. Method

2.1 SA-SCM

The SCM improves the resolution in the range direction based on extraction of the signal subspace, which uses the MUSIC algorithm [6] in the temporal direction. In order to extract the signal subspace, an FM chirp signal is transmitted a plurality of times with different carrier frrequencies. As a result, it is possible to secure the dimension of the signal subspace corresponding to the number of scatterers present on each image line. However, since multiple tansmission/reception is required for each image line, the frame rate extremely decreases when super-resolution is performed on the entire imaging area.

In order to solve the problem, the SA-SCM is realized by incorporating the SAI into the SCM. The SA-SCM transmits multiple divergent pulse while shifting the subarray for transmission. Then, the reception beamforming is performed on the echoes received by all transducer elements. Multiple line signals with different frequencies for each line are input to the SCM process.

2.1 F-DMAS

Like the DAS, the F-DMAS corrects the delay of the echoes received by many transducer elements. In the case of analytic signal representation, the phase is changed by correcting the delay, so that phase correction is also required. In the DAS, delay-corrected received echoes are added up, but in the F-DMAS, corrected received echoes are multiplied by a combination of all pairs and added. Assuming that the number of received echoes is N, the number of all combinations of pairs is

$$\binom{N}{2} = \frac{N^2-N}{2}. \tag{1}$$

Physical dimension is changed by multiplication, and therefore processing to restore the dimension is performed. That is

$$\hat{s}_{ij}(t) = sign\left(s_i(t)s_j(t)\right)\cdot\sqrt{\left|s_i(t)s_j(t)\right|}. \tag{2}$$

where s_i is i th received I-Q signal and s_j is the j th I-Q signal. From these equations, the signal after the addition is

$$y^*_{\mathrm{DMAS}}(t) = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{s}_{ij}(t) = \sum_{n=1}^{(N^2-N)/2}\hat{s}_n(t). \tag{3}$$

It is necessary to extract the double frequency band using band-pass filter in the F-DMAS of RF representation. On the otherhand, in I-Q represented F-DMAS, this filtering is not required since the result of Eq. 3 is the base band signal with no high-freuency components.

3. Performance evaluation by simulation

3.1 Simulation method

Simulation was carried out using the PZFlex which is an ultrasonic propagation simulator based on FEM (finite element method). **Figure 1** shows the simulation model. Assuming a linear array transducer composed of 64 elements, the element width and the element spacing were 0.08 mm and 0.06 mm, respectively. The target object was placed in water at a distance of 10 mm from the transducer with a diameter of 0.6 mm, a density of 900 kg/m^3, and a sound velocity of 2000 m/s. FM-chirp pulses were transmitted as divergent waves 15 times while changing the position of the transmitting subarray in the array transducer. The carrier wave frequency was randomly changed in the range of ± 0.15 MHz around 5.0 MHz. A corresponding echoes were received by all 64 elements of the transducer and were processed using the Matlab software.

3.2 Performance evaluation of SA-SCM using F-DMAS

Performmance comparison between the DAS and the F-DMAS were conducted. **Figure 2** shows the B-mode image of the SA-SCM, and **Fig. 3** shows the intensity distribution profile on the line crossing the imaging target for them.

From the results, it can be confirmed that the resolution in the range direction improves when the F-DMAS is applied. This is because the frequency band of twice the original bandwidth can be used by F-DMAS processing. Regarding the lateral direction, discontinuity does not occur in the waveform as compared with the case when the DAS is applied, but the resolution does not improve.

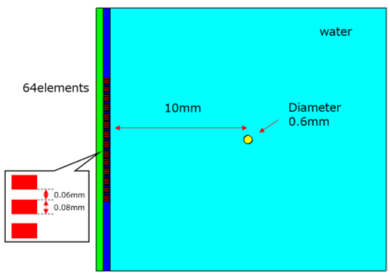

Figure1: simulation model

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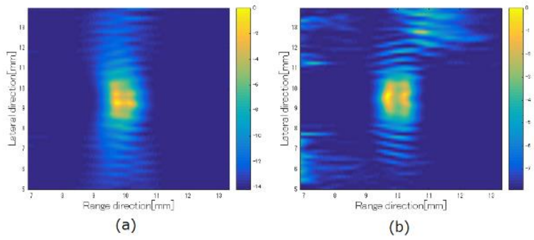

Figure2: B-mode image of the SA-SCM using (a) DAS and (b) F-DMAS.

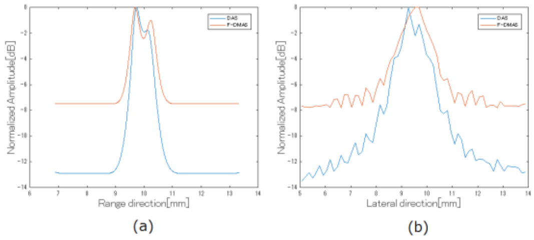

Figure3: Intensity distribution profile on the line crossing the imaging target: (a) Range direction; (b) Lateral direction

4. Conclusion

For the SA-SCM, which is a range direction super-resolution method, as a method of SA, performance was compared between cases using the DAS and the F-DMAS. Against the DAS, the F-DMAS improves range resolution, but lateral resolution does not improve. This is because the carrier frequency is disturbed due to the nonlinearity of the F-DMAS processing, so it is thought that it affected the SCM processing. In order to improve this, we are considering a method of applying the F-DMAS to the method called SCM-weighted SA proposed in [7]. In this method, the SCM is applied to the echoes received by each element before SA processing, and the result of the SCM is used as the weight for subsequent SA processing. The application of the F-DMAS to it solves the problem in this study and it is expected that lateral resolution improves.

References

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