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Super-resolution Plane Wave Beamforming Based on Frequency and Angle Compound

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1. Introduction

In high resolution ultrasonic images, using pulse compression technology, we solved the problem that shorter pulses can be generated by using wideband and high frequency signals. However, when multiple reflectors are close to each other, they cannot be separated. In order to improve this problem, SCM (Super resolution FM-Chirp correlation Method) was proposed[1]. This method uses his FM chirp signal as the transmission signal and realizes super-resolution by using the phase information of the compressed wave. To effectively apply SCM in beamforming, SCM weighted SA is proposed[2]. SCM-weighted SA improves the resolution of the received echo by multiplying the received echo of each element by the SCM result of each element, and generates an image by DAS. However, in order to implement this method, multiple transmissions and reception of signals of different frequencies are required. and the use of SCM based on multi-directional transmission has not been realized[3].

On the other hand, for high-resolution beamforming, we proposed filtered Frequency and Plane-Wave Compounding Minimum Variance Distortion-free Response beamforming (filtered-FPWC-MVDR), which transmits and receives the entire effective band all at once, and then extracts multiple narrow subbands by frequency filtering. After that, the adaptive frequency weight of each subband is calculated by MVDR. And then for each angle of subbands with adaptive frequency weight, their adaptive angle weights are calculated respectively by MVDR same. Finally Delay-And-Sum (DAS) is used for the coherence sum of the element array[4]. This method has confirmed to be effective in improving resolution.

Therefore, in order to further improve the resolution of the filtered-FPWC-MVDR, we propose to transmit and receive the the entire effective band all only once in each direction, and use a filter to extract the entire effective band into multiple sub-bands of different frequencies, perform SCM using the sub-bands. Then, the original subband is multiplied by the SCM result for each element in each transmission direction to get a new subband with SCM weights. Finally we use this subband with SCM weights for filtered-FPWC-MVDR. As a result, it is possible to improve the resolution well.

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2. Method

An FM chirp pulse is sent using the entire effective band of the probe, and L equally spaced subband selected components are extracted from the received signal. The value set as z_j which is extracted from the j-th band component of the echo received.

First, the variance-covariance matrix $\mathbf{R}$ should be calculated as follows:

$$\hat{\mathbf{R}} = \frac{1}{L}\sum_{i=1}^{L} z_j z_j^{\mathrm{H}} , \tag{1}$$

where $^{\mathrm{H}}$ is Hermitian transposition. Then, calculate the eigenvector of $\mathbf{R}$ and set the eigenvector of $\mathbf{R}$ as e. At the same time we calculate the autocorrelation function of the transmitted signal, named r. SCM is calculated as follows:

$$S(t_i) = \frac{r_i^{\mathrm{H}}\mathbf{R}_0^{-1}r_i}{\sum_{k=D+1}^{M}\left|r_i^{\mathrm{H}}e_k\right|^2} , i = 1,2,\dots,M. \tag{2}$$

where M is the sampling points of the receive echo. The eigenvector corresponding to the first D-th item spans the signal subspace. On the other hand, the eigenvectors corresponding to $M-D$ fill the noise subspace, and $\mathbf{R}_0$ is unit matrix.

Finally, the original subband z_j is multiplied by the SCM result S for each element in each transmission direction and set as x_j. we use this subband with SCM weights x_j for filtered-FPWC-MVDR.

3. Experiments

In the experiments, the transmission and reception sequences were generated using an experimental platform for medical ultrasound applications (Microsonic RSYS0003) with a sampling rate of 31.25 MHz. The number of transducer elements used for both transmission and reception in this case is 64, while the element pitch is 0.315 mm. A linear array probe (Nihon Dempa

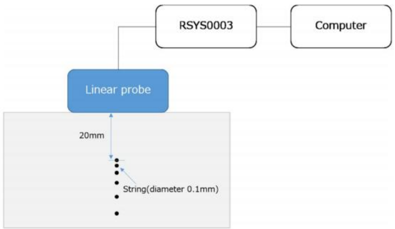

Fig. 1 Experimental setup.

Kogyo T0-1599) was also used. The signal processing step was performed using MATLAB software.

Figure 1 shows the experimental setting. We present the experimental results obtained using a soft tissue-mimicking phantom (Kyoto Kagaku US-2 multi-purpose phantom N-365), the phantom contains string wires with the same diameter of 0.1 mm. For FPWC-MVDR beamforming, subbands were used at 15 center frequencies, where each subband was equally spaced selected from the range between 4 and 8 MHz. For the transmission process, plane waves were transmitted 33 times while the angle was varied in steps of 0.5°from −8°to +8°. Equation 2 is used as a SCM-weighted output with D = 6.

4. Result and Discussion

Figure 2 illustrate the B-mode images of various methods. Figure 2(d) shows the result of Filtered-FPWC-MVDR with SCM-weighted, that is our proposed method. Compared with Figure 2(b), that is Filtered-FPWC-MVDR, the proposed method has significantly higher resolution and better background level.

Figure 3 shows the amplitude distribution profiles along the range direction and the lateral direction. The profiles of Coherent Plane-Wave Compounding (green line), the profiles of the Filtered-FPWC-MVDR (black line), the profiles of Coherent Plane-Wave Compounding with SCM-weighted (red line) and the profiles of the proposed method (blue line) are individually shown in Fig. 3. What is interesting is that the range resolution improves when only the SCM weights are used, but the lateral resolution does not change. However, in the Filtered-FPWC-MVDR, the SCM weight has an effect on the improvement of the lateral resolution. And it can be seen that the proposed method has lower background levels in the range and lateral directions.

5. Conclusion and Future Work

We have proposed a method to transmit and receive the the entire effective band all only once in each direction, and extract multiple subbands to optimize SCM as the weights for Filtered FPWC-MVDR. We can confirm that this method is very effective in improving the resolution and background level through experiments. In the future, we will conduct cyst experiments to observe whether this method is effective under weak reflection conditions.

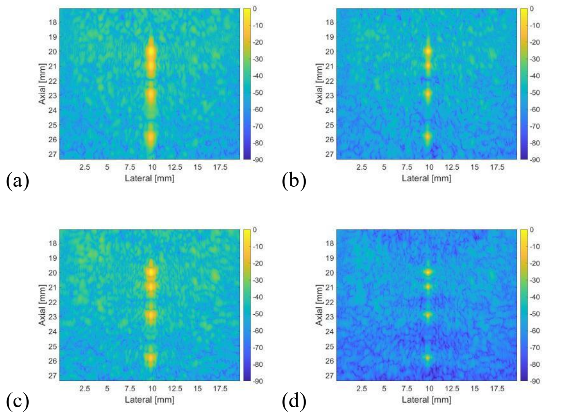

Fig. 2 B-mode images: (a) Coherent Plane-Wave Compounding; (b) Filtered-FPWC-MVDR; (c) Coherent Plane-Wave Compounding with SCM-weighted; (d) Filtered-FPWC-MVDR with SCM-weighted (proposed method).

References

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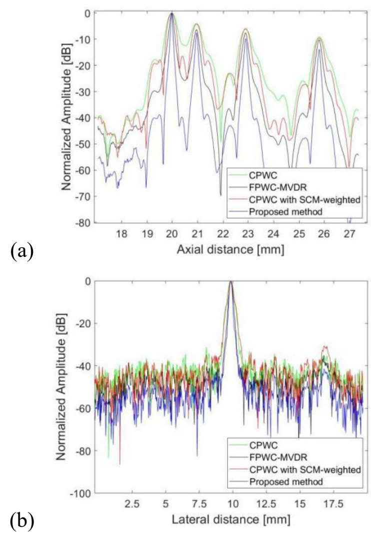

Fig. 3 Amplitude distribution profiles along (a) range direction and (b) lateral direction.