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Fundamental Evaluation of Weighted Filtered Delay Multiply and Sum Beamforming

WF-DMAS の評価検討

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1. Introduction

In medical ultrasound imaging, beamforming is a fundamental signal processing method for transmitting and receiving ultrasonic beams in a specific axis. A delay and sum (DAS) beamforming algorithm is one of the most popular techniques and has been used for many years. The DAS has an advantage on low calculation complexity but its image quality has remained to improve. Delay multiply and sum (DMAS) method was first proposed [1] in RADAR imaging applications for the early detection of breast cancer and its modified version, filtered delay multiply and sum (F-DMAS), was proposed by Matrone et al [2]. This method can improve the lateral resolution and contrast of B-mode images. Furthermore, several methods of modified DMAS have been proposed. In a previous study, a weighted filtered multiply and sum (WF-DMAS) algorithm was proposed [3]. It is one of them and consists of DMAS, weighted apodization, and cross-correlation parts. In this study, an improved WF-DMAS was proposed and the fundamental evaluation of the WF-DMAS was operated using numerical simulations.

2. Method

The proposed algorithm is illustrated in **Fig. 1**. The proposed method generates 2 F-DMAS signals at every reception. The signals received are delayed and split into 2 signal groups using 2 different apodization functions. Subsequently, 2 F-DMAS signals are developed. The number of signal pair combination to be multiplied is

$$\binom{M}{2} = \frac{M^2-M}{2}, \qquad (1)$$

where M is the number of receiving elements used for F-DMAS. Subsequently, the multiplied signal is normalized by taking a signed square root as below

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

where $s_i(t)$ is the signal of ith receiving element, and $s_j(t)$ is the signal of jth receiving element. The signal $y_{DMAS}(t)$ obtained by adding all multiplied signals is

$$y_{DMAS}(t) = \sum_{i=1}^{M-1}\sum_{j=i+1}^{M}\hat{s}_{ij}(t). \qquad (3)$$

Since the output signal contains base-band and the 2nd harmonic components, the 2nd harmonic is extracted using a band-pass filter, then the F-D MAS signal $y_{FDMAS}(t)$ is obtained.

After developing the 2 F-DMAS signals $rx_1(t)$ and $rx_2(t)$, normalized cross-correlation (NCC) is performed to calculate the degree of similarity between the signals. This process is to distinguish the mainlobe dominated signals from clutter signals because the 2 apodization functions give similar mainlobe signals and very different clutter patterns.

The obtained NCC is then filtered as below

$$STF = exp((NCC-1)\times\alpha) \qquad (1)$$

where, α is a curve parameter. This soft thresholding filter, which is newly proposed for WF-DMAS, decreases the NCC exponentially to emphasize the difference between signals. In this paper, α was set to 100.

Whereas, the F-DMAS signals are simply combined and then multiplied with the filtered NCC. Consequently, Hilbert transform and log compression are performed, and WF-DMAS signal is obtained.

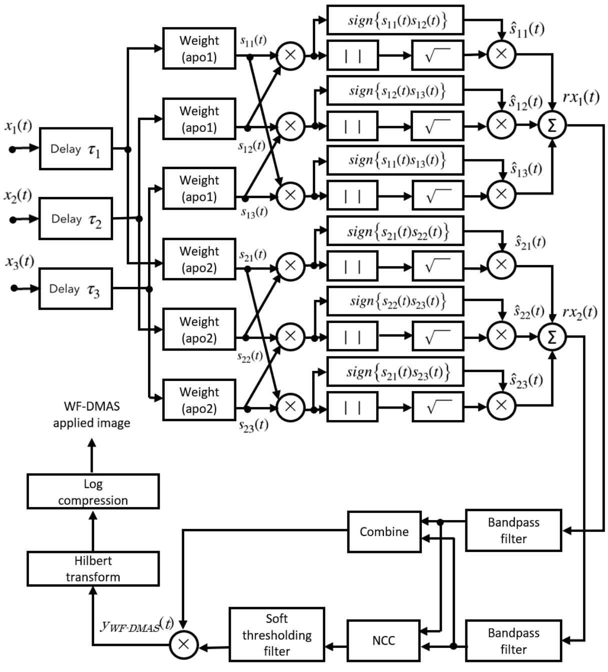

Fig. 1. Block-diagram of WF-DMAS beamformer.

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3. Results

Simulations were performed in MATLAB (The MathWorks, Natick, MA, USA) by using the Field II simulator [4]. The condition of the transducer is listed in **Table I**. A 32-element aperture was used in transmission and the focal depth was set to 15 mm. During transmission, the transducers generated a Gaussian-windowed 2-cycle sinusoidal burst at 12 MHz (68% fractional bandwidth at -6 dB). The sampling frequency was set to 100 MHz.

The obtained PSF at the transmission focal depth is shown in **Fig. 2**. The axial and lateral profiles of each method are shown in **Fig. 3**. It is noted that the mainlobe lateral width of WF-DMAS is narrower than that of F-DMAS. Although the clutter noise appears around x = 5 mm in WF-DMAS, which is greater than that of F-DMAS, the values are kept below -80 dB.

Table I. Condition of transducer.

Parameter	Value
Element number	192
Width	0.17 mm
Kerf	0.03 mm
Height	3 mm

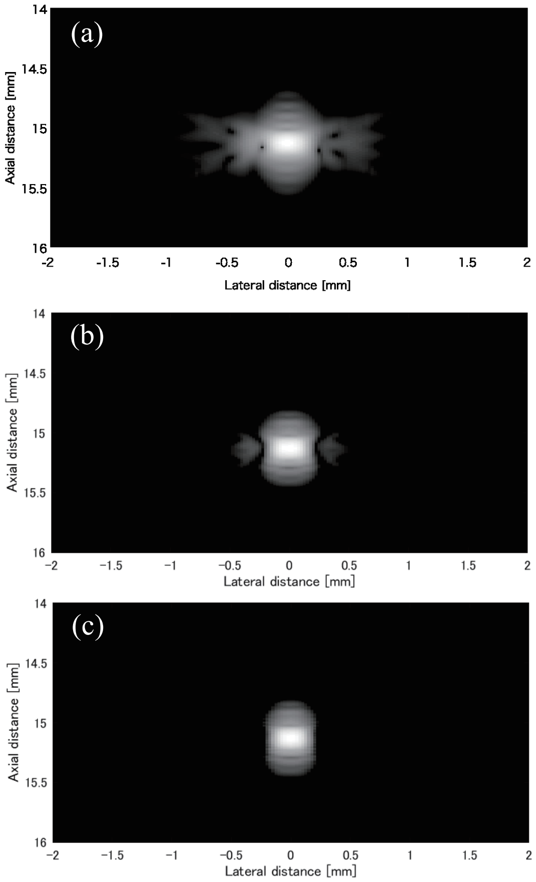

Fig. 2. PSFs at the transmission focal depth, obtained by employing (a) DAS, (b) F-DMAS, and (c) WF-DMAS.

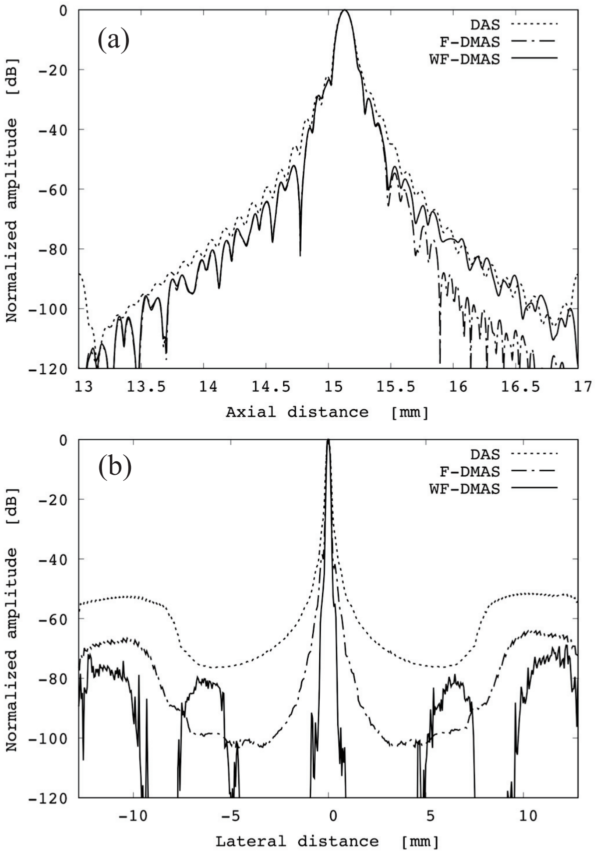

Fig. 3. (a) Axial profiles of the DAS, F-DMAS and WF-DMAS (black line) PSFs at $x = 0$ mm. (b) Two-way normalized beampatterns at $z = 15$ mm for DAS, F-DMAS, and WF-DMAS.

4. Conclusion

In this study, a fundamental evaluation of the improved WF-DMAS algorithm was carried out. As a future work, further investigation will be performed.

References

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