Least-Square Beamformer for Medical Ultrasound Imaging

医用超音波イメージングのための最小二乗ビームフォーマ

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1. Introduction

Quality of a medical ultrasonic image significantly affects the accuracy in medical diagnosis. Ultrasound beamforming methods are an important part of a series of processing for creation of an ultrasonic image. Various beamforming methods have been developed for the improvement of image quality. Recently, adaptive beamformers were introduced in medical ultrasound imaging for improvement of image quality [1,2]. Such beamformers improve the spatial resolution and contrast of an ultrasonic image. However, such beamformers requires intensive calculations, such as matrix inversion. Therefore, it is still difficult to make such adaptive beamformers practically useful. In the present study, a beamformer, which utilizes only a simple least-square method, was developed for improvement of image quality in medical ultrasonic imaging.

2. Materials and Methods

2.1 Experimental setup

In the present study, ultrasonic echoes received by individual transducer elements were acquired by a custom-made ultrasound system (RSYS00002, Microsonic) equipped with a 7.5-MHz linear array probe (PU-0558, Ueda Japan Radio) whose element pitch was 0.1 mm. Echo signals received by individual elements were sampled at 31.25 MHz.

Ultrasound echoes were acquired by the conventional line-by-line acquisition sequence. A focused transmit beam, whose focal distance was 20 mm, was created with 72 active elements, and echoes were received with 96 elements. The same procedure was repeated by shifting the positions of the transmit and receive apertures by one element to obtain 121 scan lines at an interval of 0.1 mm.

2.2 Least-square (LS) beamforming

Let us denote ultrasound echo signal received by the *m*-th transducer element by s_m. The echo signals received by *M* elements in the receive aperture were composed in a vector from:

$$\mathbf{S} = [s_0\ s_1\ \cdots\ s_{M-1}]^{\mathrm{T}}, \qquad (3)$$

where s_m is the echo signal, which is delayed on the basis of the conventional delay-and-sum (DAS) beamforming.

After the delay compensation, an echo from a receiving focal point contained in **S** becomes a direct current (DC) component across the receiving aperture. Therefore, in the conventional DAS beamforming, the output of the beamformer y_{DAS}, which corresponds to an echo from a focal point *y*, is obtained by averaging the element echo signals s_m after delay compensation as follows:

$$\hat{y}_{DAS} = \frac{1}{M}\sum_{i=0}^{M-1} s_i, \qquad (1)$$

In the present study, the accumulated element signals $u_m\ (m = 0, 1, \ldots, M-1)$ are defined as follows:

$$u_m = \sum_{i=0}^{m-1} s_i, \qquad (2)$$

where $u_0 = 0$.

As described above, an echo *y* from a focal point becomes a DC component in element echo signals s_m after delay compensation. Therefore, the accumulated element echo signal u_m is modeled as follows:

$$\hat{u}_m = y \cdot m + n, \qquad (3)$$

where *n* is a bias induced by additive noise. Let us define the mean squared difference α between the measured accumulated element signal u_m and the model $\hat{u}_m$ as:

$$\alpha = \sum_{m=0}^{M-1} \{u_m - (y \cdot m + n)\}^2. \qquad (4)$$

The least-square estimates $\hat{y}$ and $\hat{n}$ of the echo from the focal point and the bias due to noise are obtained by setting the partial derivatives of α with respect to *y* and *n* to zero as follows:

$$(\hat{y}, \hat{n}) = \arg\min_{y,n} \alpha. \qquad (5)$$

The least-square difference $\alpha_{\min}$ is obtained by substituting $\hat{y}$ and $\hat{n}$ into Eq. (4). In the present study, a weighting factor *w*, which emphasize an echo from a focal point, was defined as follows:

$$w = \frac{|\hat{y}|^2}{\alpha_{\min}}. \qquad (6)$$

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The final output y_{LS} of the proposed least-square (LS) beamformer is obtained as follows:

$$\hat{y}_{LS} = w \cdot \hat{y}. \tag{7}$$

3. Experimental Results

In the present study, an ultrasound imaging phantom (040GSE, CIRS) was used for evaluation of image quality. **Figures 1**(a) and 1(b) show B-mode images of the string phantom obtained by the conventional DAS beamforming and proposed LS beamforming. As can be seen in Fig. 1, the lateral spatial resolution was improved significantly by the proposed LS beamforming. The lateral full widths at half maxima (FWHMs) obtained by the conventional DAS beamforming and proposed LS beamforming were 0.79 mm and 0.17 mm (at a depth about 18 mm), respectively.

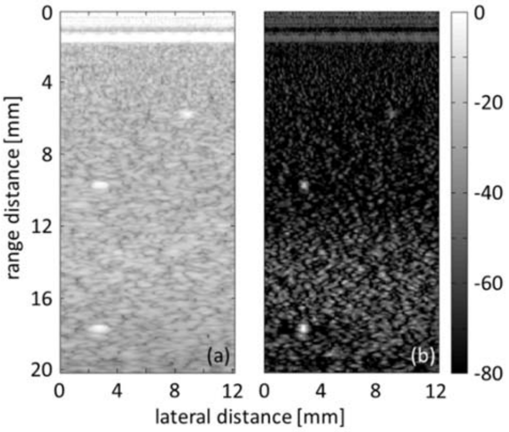

Fig. 1: B-mode images of string phantom obtained by (a) conventional DAS beamforming and (b) proposed LS beamforming.

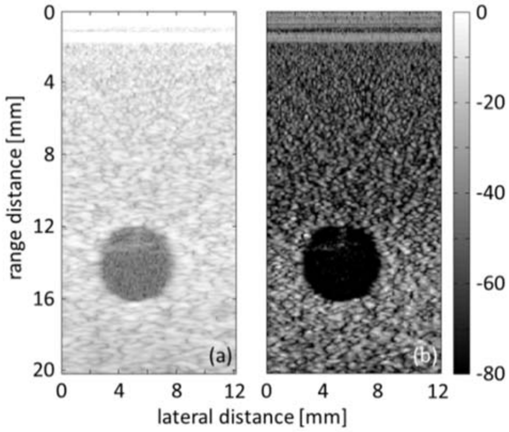

Fig. 2: B-mode images of anechoic phantom obtained by (a) conventional DAS beamforming and (b) proposed LS beamforming.

Figure 2(a) and 2(b) show B-mode images of the cyst phantom obtained by the conventional DAS beamforming and proposed LS beamforming. Image contrast was improved from 5.57 dB to 5.99 dB by the proposed LS beamforming.

In Figs. 1 and 2, the spatial resolution and contrast were improved by the proposed LS beamforming significantly, but only echoes in the region around the focal depth (20 mm) were enhanced. Such an effect would be suppressed by setting multiple transmit focal points.

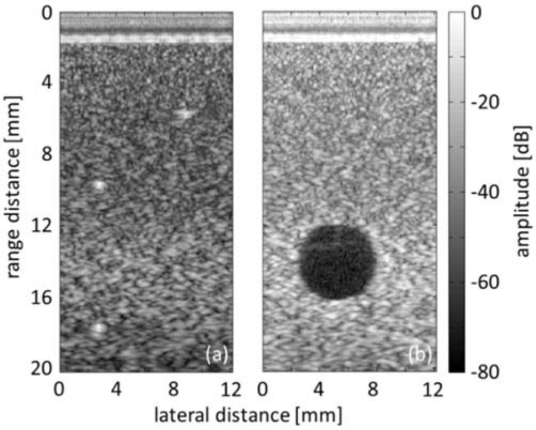

Fig. 3: B-mode images of (a) string and (b) cyst phantoms obtained by modified APES beamforming.

The proposed method was also compared with an adaptive beamformer, *i.e.*, modified amplitude and phase estimation (mAPES) beamformer [3]. **Figures 3**(a) and 3(b) show B-mode images of (a) string and (b) cyst phantoms obtained by mAPES beamforming. The spatial resolution and contrast obtained by the mAPES beamforming were 0.21 mm and 5.95 dB, respectively. The performance of the proposed LS beamforming was similar that of the mAPES beamforming, while the proposed method is based on only the simple least-square estimation and computationally efficient.

6. Conclusion

In the present study, a beamforming method based on the least-square method was developed for improvement of the spatial resolution and contrast in ultrasonic imaging with much less computational complexity than minimum variance based adaptive beamformers. The experimental results showed that the proposed method realized the performance similar to that obtained by an adaptive beamformer

References

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