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Basic study on improvement of an axial resolution by correcting initial phases of photoacoustic waves in photoacoustic tomography

光超音波トモグラフィにおける光音響波の初期位相を考慮した深さ分解能の改善に関する基礎検討

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1. Introduction

Photoacoustic (PA) imaging can visualize living tissues selectively by using a proper-wavelength-laser. The PA waves is generated based on a principal of photo-thermal phenomenon[1)]. The imaging modality[2)] can be classified such as optical-resolution photoacoustic microscopy (OR-PAM)[3)], acoustic-resolution photoacoustic microscopy (AR-PAM)[4)], and photoacoustic tomography (PAT)[5)].

A real-time-3D PA imaging system was developed by employing a spherically curved array transducerfor clinical application[6,7)]. In the system, a spatial resolution less than 100 µm could be achieved with a frame rate of 10-20 volumes per second (vps).

The previous paper reported that the PA waveform was dependent on a time-profile of the laser and a shape of a PA target[8)]. In the image reconstruction[6,7)], a thresholding process was employed to suppress a first side lobe level. The thresholding effect may be enhanced by correcting an initial phase of the PA waves, which makes the waveform transformed to be an unipolar.

In this paper, a basic study is conducted by using a spherical phantom and a vessel phantom to compare a time side lobe level in the images reconstructed by the phase correction method.

2. Materials and methods

2.1 Experimental setup

Fig. 1 shows a schematic of an experimental setup. The spherically curved array transducer consisted of 256 elements of 1-3-composite with equal area, forming 7 tracks of approximately equal width with the center frequency of 12 MHz (Japan Probe Co., Ltd., Kanagawa, Japan). A hole of 10.4 mm diameter was in the center of the transducer to irradiate targets with a laser. The PA signals were acquired by a programmable acquisition system with 256 Tx/Rx channels (Vantage 256, Verasonics Inc., Redmond, WA, USA). The sampling frequency was 62.5 MHz. The system was connected to a pulse generator (DG535, Stanford Research Systems Inc., CA, USA) to synchronize data-acquisition. A short-pulsed (< 10 ns) Nd:YAG diode-pumped Q-switched laser with second harmonic generation (SHG) (Q1C; 532 nm, 10 Hz, 5 mJ, Quantum Light Instruments Ltd., Vilnius, Lithuania) was used for generation of PA signals.

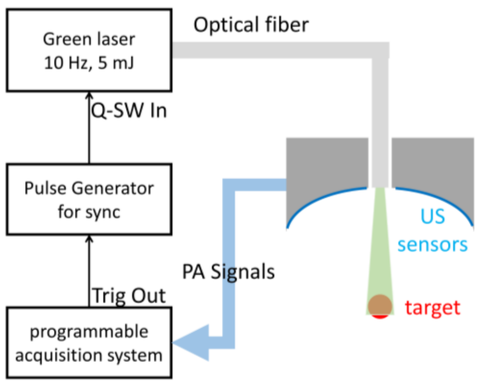

Fig. 1 Schematic of an experimental setup.

In this paper, a single polyamide particle 50 µm in diameter (Polyamid seeding particles diameter 50 µm, Dantec Dynamis A/S, Skovlunde, Denmark) and the vessel phantom were used as the PA imaging targets. The vessel phantom was made by injecting red ink into a silicon tube with inner and outer diameter of 100 µm and 300 µm.

2.2 Correcting initial phases of PA waves

In the reconstruction method, a Wiener filter[9)] was employed to restore a bandwidth of the PA signal and enhance the thresholding effect[7)]. **Fig.**

2(a) shows the concept of the reconstruction. The Wiener filter $M(\omega)$ is obtained by a following equation[9].

$$M(\omega) = \frac{H^*(\omega)}{|H(\omega)|^2 + \beta \frac{P_N(\omega)}{P_S(\omega)}}, \quad (1)$$

where $H(\omega)$, $P_N(\omega)$ and $P_S(\omega)$ are frequency spectrums of the transfer function, the averaged PAS level, and the noise level, respectively. The Wiener filter with an arbitrary phase was applied to the PA signals received by each channels in a Fourier domain as in (2). **Fig. 2(b)** shows the concept of the proposed method.

$$RF_{WF}(i,t) = IFFT[RF(i,\omega) \cdot M(\omega) \cdot \theta_{arb}], \quad (2)$$

where $RF_{WF}(i,t)$ is the Wiener filtered PA signal θ_{arb} is the arbitrary phase, and $IFFT[*]$ is an inverse Fourier transform operation, respectively. The Wiener filtered signal was used as the input to the DAS reconstruction.

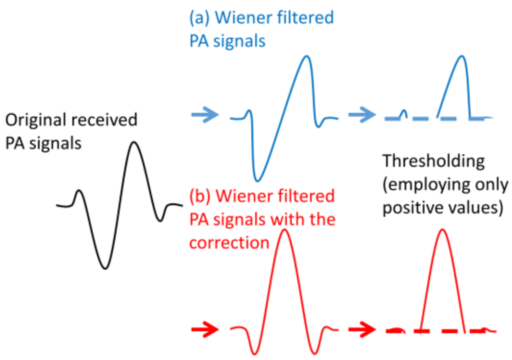

Fig. 2 Concept of (a) the original reconstruction method, and (b) the proposed method.

3. Results and discussions

Figs. 3 show a PA B-mode image reconstructed by (a) the original reconstruction method, and (b) the proposed method with the correcting phase of 90 deg., respectively. The proposed method suppressed the time side lobe levels by -8.7 dB with keeping the spatial resolution.

4. Conclusions

In this paper, the basic study was conducted by using the two phantoms to compare the time side lobe level in the reconstructed images. The time side lobe level could be suppressed by correcting the initial phase of the PA signals.

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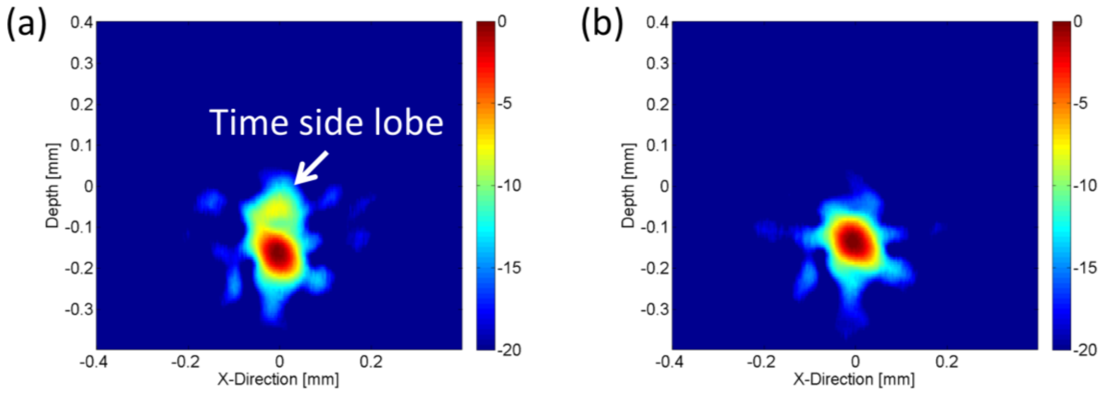

Fig. 3 PA B-mode images reconstructed by (a) the original reconstruction method, and (b) the proposed method.

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