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Reconstruction of optical absorption distribution for backward optoacoustic imaging

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Abstract — In this paper, we present a reconstruction algorithm for backward mode optoacoustic imaging. The algorithm is developed from the optoacoustic wave equations and takes advantage of the simplification associated with line focusing, which is implemented with a synthetic aperture focusing and adaptive weighting method. Computer simulations and experiments were conducted to verify efficacy of the algorithm. Performance differences between numerical simulations and the experiments will be presented and discussed.

Introduction- In biomedical applications, optoacoustic (OA) imaging takes advantage of high optical contrast and low acoustical scattering in tissue. The basic principle of this technique is the thermoelastic effect: A laser pulse irradiates a sample that induces a rapid temperature expansion, and then generates ultrasound waves. In backward mode OA imaging, the ultrasound waves are detected by the transducer located on the same side as the laser beam [1]. In several recent papers, the reconstruction methods of the optical absorption distribution, which contains the information of tissue architectures, were proposed. One of the methods is the synthetic aperture focusing technique (SAFT) [2]. However, only the edges of the absorption distribution are effectively reconstructed. In this research, an effective reconstruction algorithm is proposed. The idea of this algorithm is to reduce the OA wave equation from 3D to 1D by line focusing via the SAFT and the adaptive weighting technique [3]. The SAFT is used to improve both the signal-to-noise ratio and the lateral resolution, and the adaptive weighting technique is used to provide the uniform lateral resolution along the depth direction. After applying these techniques a narrow OA radiation pattern is achieved. Each scan position on the scan line receives only the pressure waves propagated from the sources located alone the virtual direction, which is perpendicular to the scan line in backward OA imaging. In the proposed algorithm, the absorption profile can be obtained by integrating the focused pressure waves:

$$A(z)\big|_r = \frac{4\pi \cdot z}{H} \cdot \int_{-\infty}^{t} p(\tau)\Big|_r \, d\tau \tag{1}$$

where $p(\tau)$ is the focused pressure waves at spatial position r and $A(z)$ is the absorption distribution at the depth z that is the product of the spatial laser irradiation pattern and the distribution of tissue absorptions. The constant H consists of the densities and Grüneisen coefficient in tissue. By applying Eq.(1), the absorption distribution at each scan position r can be obtained. The image of absorption distribution can be achieved by applying this algorithm with all scan channels on the scan line.

Materials and Methods – In order to demonstrate the proposed algorithm, 3D backward mode OA imaging computer simulations and experiment have been implemented. In the simulation, the OA signals in each channel on the scan line were created by applying the OA wave equation with a 4-mm thickness phantom. These signals were processed by the traditional and the proposed reconstruction algorithm. For experiments, an OA scanning system has been built up. The scanning system mainly consists of a Q-switch Nd:YAG laser with a 1mm diameter fiber output, a wideband needle hydrophone, and a two-dimension translation stage. A dyed polyvinyl alcohol (PVA) phantom with a size of 6*2.5*3.5mm, which is submerged in water with a distance of 9mm under the hydrophone tip is used to be the investigate sample. The sound waves acquired by the hydrophone are amplified and recorded by an ultrasound pulser/receiver and a personal computer with a 100-MHz DAQ card respectively.

Results – The A-line signals at the middle of the phantom are processed in both the traditional and proposed algorithms, as shown in Fig.1. A theoretical result is simulated and illustrated as a comparison. It is clear that the traditional reconstruction algorithm shows only the edges of the absorption profile. By applying the proposed

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algorithm, the reconstructed profile is more similar to the rectangular shape. In the experiment results, the theoretical profile becomes an exponential decay along the depth axis from the top (9 mm) to the bottom (11.5 mm) of the phantom that caused by the Beer's law of the optical energy decay. In the traditional backward OA imaging, the signals are processed by the SAFT to narrow the radiation pattern. Consequently, it also displays the edges of the phantom. By applying the proposed algorithm, the profile becomes similar to the theoretical result. However, the profile is distorted by the frequency response of the hydrophone due to the high-pass characteristic.

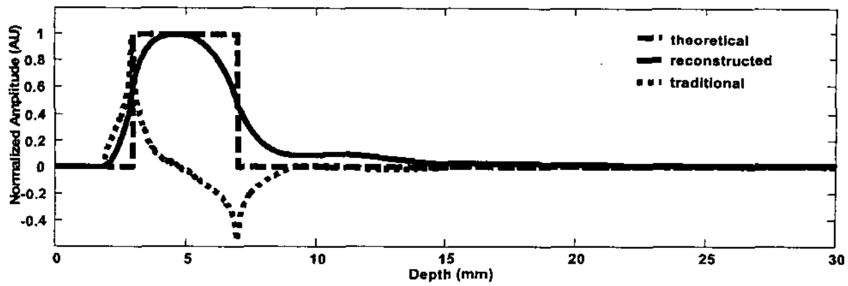

Figure 1. Simulation results represented in A-lines, including the theoretical absorption profile (dashed), the reconstructed (solid), and the traditional (dotted).

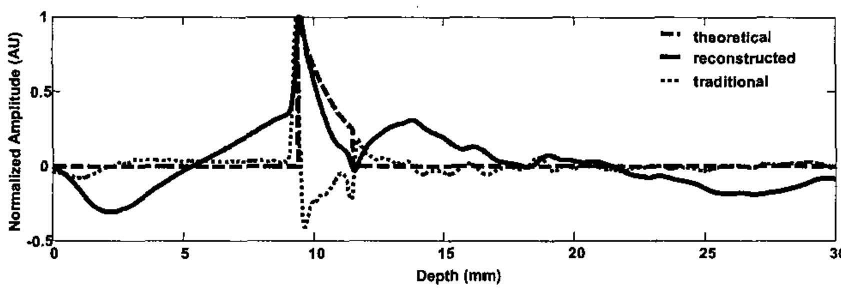

Figure 2. Experimental results

Conclusions- In this research, we proposed a reconstruction algorithm for OA imaging. This algorithm was developed from the well-known three-dimensional OA wave equation. In order to achieve a narrow radiation pattern, which is essential for the algorithm, the SAFT and adaptive weighting technique were adopted. The simulation and the experimental results demonstrated that the proposed algorithm effectively reconstructed the absorption distribution of the sample in the backward mode OA imaging. However, the frequency response around DC of the hydrophone affected the measured acoustic waveforms, and thus affected the reconstruction accuracy. Thus, the future work will focus on deconvolving of the hydrophone's frequency response.

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