2E2-3

Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 195-196
3-5 December, 2014

Photoacoustic Image Quality Enhancement by Estimating Mean Sound-Speed Based on Optimum Focusing

最適フォーカシングに基づく平均音速推定法を用いた光超音波画質の向上

Bing Cong[1†], Kengo Kondo[2], Makoto Yamakawa[3], and Tsuyoshi Shiina[1] ([1]Dept. Human Health Sci., Grad. School Med., Kyoto Univ.; [2]Int. Med. Sys. Unit for Fruitful Healthy-Longevity Soc., Kyoto Univ.; [3]Adv. Biomed. Eng. Res. Unit, Kyoto Univ.)
丛 冰 [1†], 近藤 健悟 [2], 山川 誠 [3], 椎名 毅 [1] ([1] 京大院 医, [2] 京大 総合医療開発, [3] 京大 先端医工)

1. Introduction

Photoacoustic (PA) imaging is a noninvasive imaging modality for visualizing the structure and function of soft tissues. It has the potential to structurally image animal or human organs, such as the breast and the brain, with simultaneous high contrast and high spatial resolution [1].

Existing reconstruction algorithms for PA imaging are based on the assumption that the sound speeds in the tissue are homogeneous. However, the variations of sound speeds in the tissue can be as great as 10%, which lead to distortion and blurring of absorber in the reconstructed images [2]. To improve the PA image quality, using the sound speed distribution obtained from ultrasonic transmission tomography (UTT) has been proposed [3], but this method requires addition complicate experiment equipment, substantial mound of numerical computation and circle detection geometric structure around the absorbers in two dimensions (2D), which is usually distant for human organs in practice.

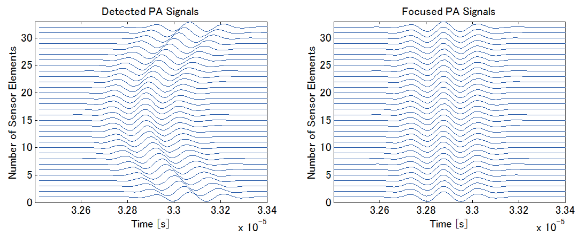
As a low cost alternative compensation method, one mean sound speed which can be estimated based on optimum signal focusing to provide best image quality has been proposed [4]. We apply this approach to received PA signals by iteratively estimating optimum mean sound speed. Then, the estimated sound speed can be used to reconstruct PA images. The proposed method is demonstrated with numerical simulation models to verify its performance and effectiveness.

2. Method

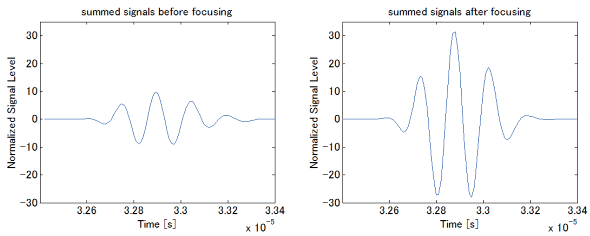
Fig.1(a) shows the detected PA signals generated from a point target by each sensor element at different time. To focus the PA signals at a reconstruction point (x,z), the receive focusing delay time for the nth element (x_n, z_n) can be calculated by

$$d_n = \frac{\sqrt{(x-x_n)^2+(z-z_n)^2} - F}{c} \quad (1)$$

where F is the depth of reconstruction point, c is the real sound speed. As shown in **Eq.1,** receive focusing is a function of the sound speed. If the sound speed used to calculate focusing delay times is not equal to c, the phase distortions occur and lead to the decreased in intensity of summed PA signals (**Fig.2(a)**). Otherwise, if the sound speed is equal to c, the delayed PA signals are in phase (**Fig.1(b)**) and the intensity of summed signals can be coherently enhanced (**Fig.2(b)**).



(a) (b)
Fig.1 Detected and focused PA signals.



(a) (b)
Fig.2 Summed PA signals before and after focusing.

The average sum of absolute difference of focused PA signals can be utilized as the focusing quality factor Q to evaluate whether the PA signals are optimally focused and can be calculated by

$$Q \overset{c=c+\Delta c}{=} \frac{1}{M \times N} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} | p_n(m) - \mu_{p(m)} | \quad (2)$$

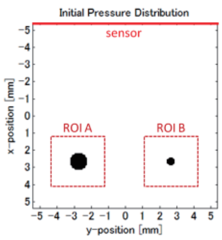
where M and N are the number of focal points and sensor elements, p is the focused PA signals and μ is the mean value of focused PA signals. In the optimum mean sound speed estimation, the focusing quality factor Q is iteratively calculated for each scan line in region of interest (ROI) while changing the sound speed. The sound speed providing the minimum value of Q is determined as the optimum mean sound speed for ROI. Then the

† E-mail:cb5515@gmail.com

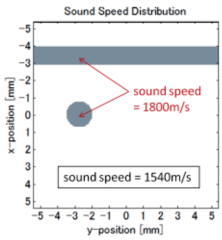
estimated mean sound speed is used to reconstruct PA image by 2D fast Fourier transform (FFT) reconstruction algorithm. Finally, compared to the conventional method, the vertical profiles of reconstructed targets are plotted, respectively.

3. Numerical Simulation

The simulation model is demonstrated with two disc initial pressure distribution (**Fig.3(a)**), which diameters are 0.5mm and 1mm, respectively, and heterogeneous sound speed distribution (**Fig.3(b)**), where the gray area with higher sound speed (1800m/s) compared to surrounding area (1540m/s). The PA signal propagation is simulated by a k-wave toolbox [5], which is similar to finite element method (FEM).



(a)

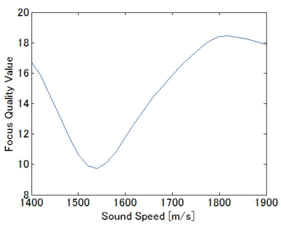


(b)

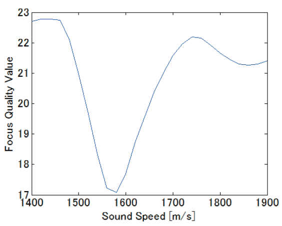
Fig.3 Initial pressure distribution and sound speed distribution.

4. Result

Fig.4 shows the calculated focusing quality value Q from 1400m/s to 1900m/s with 10m/s interval. The minimum value was achieved at 1540m/s (**Fig.4(a)**) and 1580m/s (**Fig.4(b)**) for ROI A and B, respectively. The reconstructed PA images using the estimated mean sound speeds were shown in **Fig.5**. The vertical profile of reconstructed two disc targets were shown in **Fig.6** and **Fig.7**, which indicate that the proposed method can provide higher contrast and better spatial resolution.

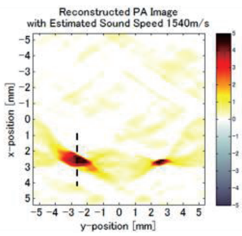


(a)

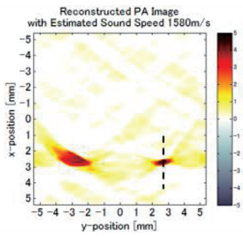


(b)

Fig.4 Estimated focusing quality value Q for various sound speeds in ROI A and B, respectively.



(a)



(b)

Fig.5 Reconstructed PA images using the estimated mean sound speeds for ROI A and B, respectively.

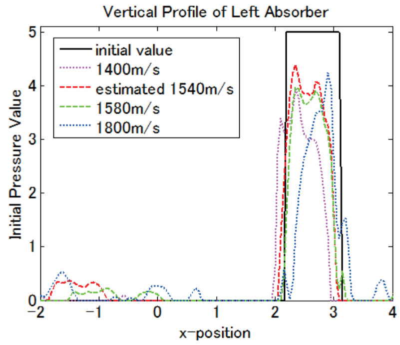


Fig.6 The vertical profile of left target as shown in Fig.5(a).

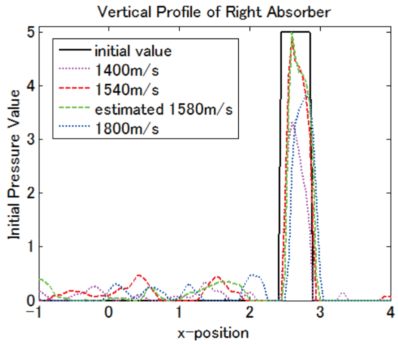


Fig.7 The vertical profile of right target as shown in Fig.5(b).

Nevertheless, there are several further discussions. First, the estimated sound speed can provide higher image quality, but is not the true value. Second, the proposed method requires prior information such as the rough locations of targets. This limitation can be relieved by using ultrasound (US) B-mode image or reconstructing PA image by using a general sound speed first, then selecting ROI and tuning the sound speed by using the proposed method. Finally, the use of an iterative estimation procedure may increase the computational time due to the size of ROI.

5. Conclusion

The mean sound speed estimation based on optimum focusing of PA signals can improve the contrast and spatial resolution of reconstructed targets. In future work, we will demonstrate the method by using mimicking phantoms and assessing the potential for clinical treatment.

References

1. Minghua Xu and Lihong V. Wang: Rev. Sci. Instrum. 77 (2006) 041101.
2. F. A. Duck: *Physical Properties of Tissue: A Comprehensive Reference Book* (Academic Press, NY, 1990) p.75.
3. Xing Jin and Lihong V. Wang: Phys. Med. Biol. **51** (2006) 6437.
4. C. Yoon, Y. Lee, J. H. Chang, T. Song and Y. Yoo: Ultrasonics **51** (2011) 795.
5. B. E. Treeby and B. T. Cox: Jan. of Biomed. Opt. **2** (2010) 021314.