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Investigation on the method for estimation of average speed of sound with consideration of multi-reflection

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1. Introduction

Several research groups including our group have proposed methods for estimation of average speed of sound (SoS) and SoS itself[1-9]. The average SoS is an important factor for image reconstruction. Also, as the SoS is proportional to the bulk modulus of tissues, the elasticity of the tissue can be evaluated based on the SoS. We have focused on coherence factor (CF) [1-3, 10], signal-to-noise ratio (SNR)[2], and variance of phase information of signals received by elements[9] for the estimation of the average SoS.

Our previous study[9] reported that the estimation method of the average SoS using the variance of the phase could suppress effects from the boundaries between tissues with different SoSs compared to the method using the CF. However, in both the cases, as multi-reflected waves occur at the boundaries, the effects on the estimation cannot be avoided actually. Hence, we propose a method for the estimation of the average SoS with consideration of the multi-reflection. In this paper, we verify the feasibility of the proposed method by performing numerical simulations using k-Wave software[11, 12].

2. Materials and Methods

2.1 Method for estimation of average SoS

In the estimation of the average SoS, a quality index for receive beamforming, such as CF, SNR, and variance of phases, is calculated at different average SoSs. When calculating the index at each average SoS, the assumed average SoS which maximizes the calculated index is determined as the estimated average SoS. In the present study, the CF and variance of the phases were chosen as the quality index for the estimation. Also, the average SoS for the calculation was changed from 1450 m/s to 1650 m/s at an interval of 2.5 m/s. In this paper, we will describe the results obtained using the variance of the phase of the element signals.

Ultrasound compound imaging[13] was employed for acquisition of signals, and steering angles for the plane wave transmissions were set from -15 to 15 degrees with a step of 0.25 degrees. The multi-reflected waves occur at the boundary parallel to the wave front of a transmitted wave, and the surface of skin and structures of tissues are typically parallel to the ultrasound probe surface. Hence, in the proposed strategy, the data acquired at steering angles from -5 to 5 degrees was not used for the estimation of the average SoS. Also, the data acquired at steering angles more than 10 degrees was not used to avoid an effect from a grating lobe. In the present study, we investigated the estimated results with four different sequences of the steering angles as follows; [-15 to 15 degrees], [-5 to 5 degrees], [-10 to -5, and 5 to 10 degrees] and [-15 to -10, and 10 to 15 degrees].

In this numerical simulation, a linear probe with a center frequency of 7.5 MHz was simulated. The signals from a numerical simulation phantom were acquired at a sampling frequency of 31.25 MHz.

2.2 Simulation experiments

Fig. 1 shows a distribution of assigned SoSs in a three-layer phantom for the numerical simulation. The three-layer phantom consisted of skin, fat, and muscle layers from the surface. Thicknesses of the skin, fat, and muscle layers were set at 1, 4, and 30 mm, respectively. Also, according to the previous papers[4, 14, 15], the SoSs of the three layers from the surface were set at 1670, 1474, and 1576 m/s, respectively.

An estimation accuracy was evaluated based on an absolute bias error (ABE) between the true and estimated average SoSs in a region of interest R as,

$$\mathrm{ABE} = |\mathrm{E}_R[\hat{c}_e - c_t]|, \tag{1}$$

where variables $\hat{c}_e$ and c_t are the distribution of the estimated and true average SoS in the region R, respectively. The true average SoS was calculated

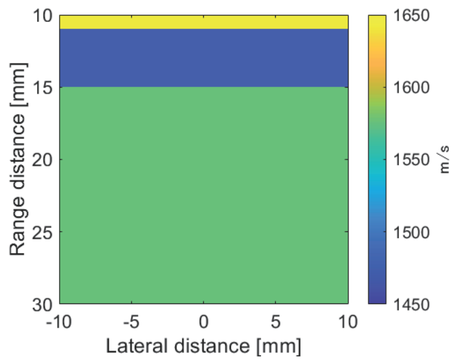

Fig. 1 Distribution of assigned SoSs in a three-layer phantom for the numerical simulation

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from the assgined SoS in Fig. 1. Also, $E_R[*]$ denotes an average operation in the region R. Also, the region R was set at from -3 to 3 mm in the lateral direction and from 10 to 30 mm in the range direction, respectively.

3. Results and Discussions

Fig. 2 shows a B-mode image of the three-layer phantom. **Fig. 3** shows comparison of the estimated average SoSs when the steering angles were as follows; [-15 to 15 degrees] and [-10 to -5, and 5 to 10 degrees]. Note that a legend of "Var" corresponds to an abbreviation of "usage of variance". The estimates obtained using the proposed strategy almost conformed to the true ones, and the bias error was 12.2 m/s. Also, the bias errors obtained using different transmission sequences of [-15 to 15 degrees], [-5 to 5 degrees] and [-15 to -10, and 10 to 15 degrees] were 9.58, 14.9, and 20.3 m/s, respectively. Although the bias error obtained using a transmission sequence of [-15 to 15 degrees] was lowest of four, the estimates using this sequence was overestimated as shown in Fig. 3. Meanwhile, outliers were observed in the estimates obtained using the proposed strategy near the boundaries and in a deeper region. It's considered that this was because of a lower SNR in the deeper region. These results indicated that the proposed strategy might suppress the effect from the multi-reflection.

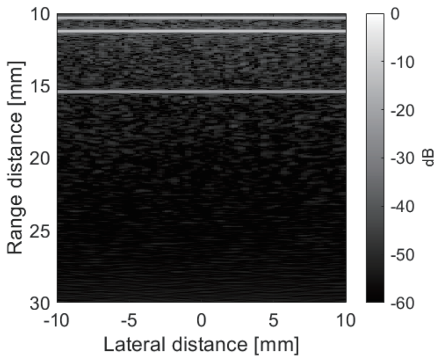

Fig. 2 B-mode image of the three-layer phantom

4. Conclusion

We proposed the method for the estimation of the average SoS with consideration of the multi-reflection. The proposed strategy does not employ the data acquired when the wave front of the transmission is parallel to the surface of the skin and structures of the tissues for the estimation. In this paper, we verified the feasibility of the proposed method by performing the numerical simulations with the three-layer phantom using k-Wave software. The results of the numerical simulation indicated that the proposed strategy might suppress the effect from the multi-reflection.

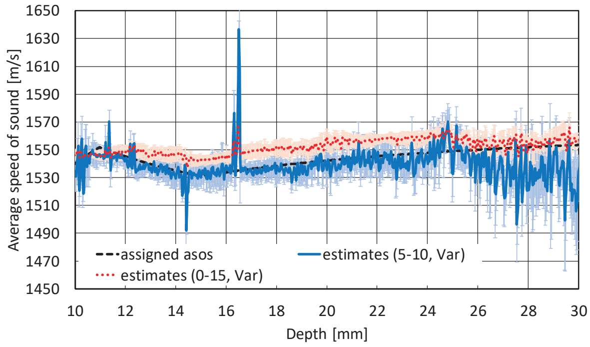

Fig. 3 Comparison of the estimates

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