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Verification of effects caused by echo separation method in speed of sound analysis at ultra-high frequency

超高周波帯域において波形分離手法が音速解析へ与える影響の検証

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1. Introduction

Applying the autoregressive (AR) model in exponential to deconvolute echos is known as one of the method to analyze speed of sound (SoS) by scanning acoustic microscopy (SAM) in practical use. However, the accuracy of analysis with AR model in ultra high frequency (< 100 MHz) is unknown. In addition, the influence of the surface shape of the target sample on the accuracy of SoS analysis has not been deeply examined. This study aims to understand the relationship between measuring conditions, wave separation by AR model and the accuracy of SoS analyze through the echo simulations using Finite-difference time-domain method (FDTD) method.

2. Theory and Experiments

2.1 Analysis method of speed of sound

In the SoS analysis using SAM, ultrasound is irradiated to the sliced sample set on the glass plate via the water (Fig. 1). When the echo reflected from the surface of glass plate directly irradiated at location without tissue sample used as a reference echo, the SoS of sliced tissue sample is given as

$$C = \frac{t_s}{t_s - t_d} C_0. \tag{1}$$

where, t_s is the time of flight subtracted the one of the reference echo (ToF-difference) of the echo from the surface of tissue, t_d is the ToF-difference of the echo from the bottom of the sample, and C_0 is the SoS of water [1]. To calculate the SoS, echo from the tissue should be separated in original components, because echo from the tissue consists of multiple interfered waves. AR model which separate wave components from interfered signal is given as

$$X_i = \sum_{k=1}^{N} a_k X_{i-k} + e_i . \tag{2}$$

where, X_i is the observed value (the spectrum obtained by diving the spectrum of echo from the tissue by the spectrum of the reference echo), N is the order of the AR model (AR order), a_k is the model parameter, and e_i is the error [2]. The order of AR model is the number of components echo from the tissue will be separated in and one of the important parameter which should be given in advance.

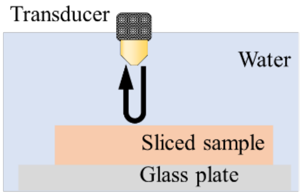

Fig.1 Measurement method

2.2 Echo simulation by FDTD

The wave propagation in two dimensions was simulated by finite-difference time-domain (FDTD) method using MATLAB (The MathWorks Inc., Natick, MA). The target tissues were set on a glass plate, and ultrasound pulse of 250 MHz was irradiated to it via the water. The acoustic impedance of the tissue sample was imitated the actual liver tissue, and the basic thickness of the tissue was 6 µm, and the signal to noise ratio was 50 dB. The focus depth and the lateral resolution in focus depth were 700 µm and 7 µm, respectively.

2.3 SoS analysis method

To understand the relationship between the condition of biological tissue and the accuracy of echo separation by AR model, the simulation was performed on the different surface shapes (6 µm flat shape and actual sample shape). The focus depth of the ultrasound beam was set on the surface of 6 µm flat sample, and the distance of the transducer and the glass plate was fixed. The AR order was varied from 2 to 12 to understand how the accuracy of echo separation affects to the analysis result. The SoS of sliced sample and water were set to 1498 and 1549 m/s, respectively.

4. Results and discussions

Figure 2 shows the propagation images of echo from each tissue sample. In a flat surface sample shown in Fig. 2(a), echoes are obtaining almost as equivalent to the shape of the transmit beam. In the results of actual thin sliced liver samples that have complex surface shapes obtained as the results of laser scanning, many interferences of echoes were confirmed as in Figs. 2(b) and 2(c).

The calculated SoS from separated echo components (eg. from sample surface, from glass surface, multiple reflections, etc.) by AR model is shown in **Fig. 3**. The accuracy of SoS analysis was low when the AR order was 2 in the case of sample 1. From this result, it can be confirmed that echo components other than echo from the surface and bottom of tissue (e.g. interference, multi reflection) were intermingled to observed echo signal even at the sample has a simple flat surface. Since the analysis accuracy of SoS is also low when the AR order was 9 or more, it is assumed that the observed echo of sample 1 had 2 to 6 minutes interference and/or noise components in addition to echo from the surface and the bottom of the tissue.

For sample 2 and sample 3 imitating actual liver samples, SoS could not be calculated when the AR order was 3 or less. That is, the AR model cannot separate echoes from the sample surface and the back surface. In these cases, it is understandable that more minute interference signals are mixed in the observation signal as compared with the flat sample, since the accuracy of degradation of SoS evaluation accuracy is small when the AR order is 9 or more. The reason why the result of sample 3 is better than sample 2 is that the backscattering intensity to the transducer is strong and the nonlinearity is low as shown as in Figs. 2 (b) and 2 (c).

Conclusion

The wave propagation in SAM on ultra-high frequency ultrasound was simulated using FDTD method. The appropriate AR order and the accuracy of SoS analysis was affected by the surface shape of sliced samples. Comprehensively considered, if the measurement conditions were similar to these experiments, 7th or 8th order is appropriate to SoS analysis.

Acknowledgment

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References

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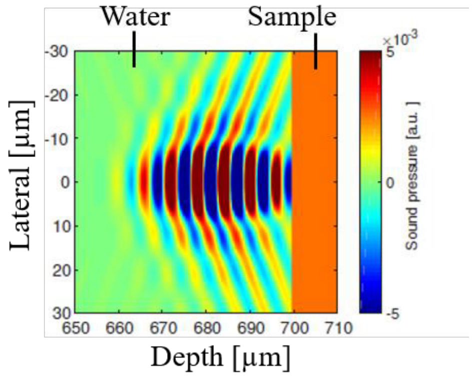
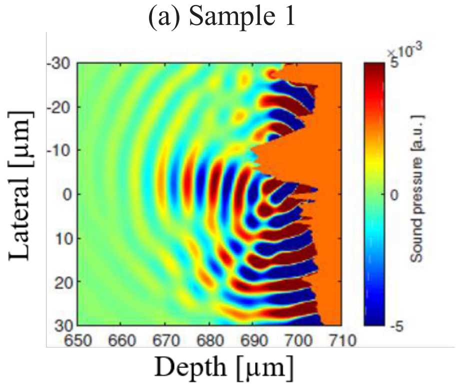
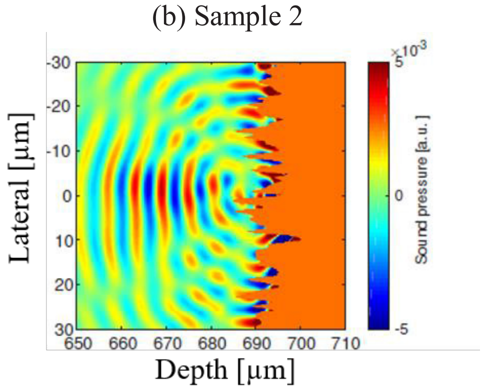


(a) Sample 1



(b) Sample 2



(c) Sample 3

Fig.2 Echo propagation image of sample 1 (a), sample 2 (b), and sample 3 (c).

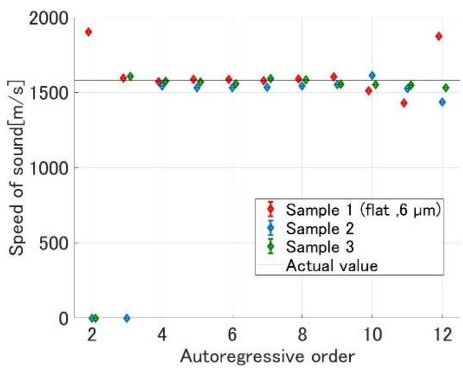


Fig.3 Calculated SoS of each sample.