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Tissue Elasticity Imaging System based on Time Reversal Process of Shear Wave

剪断波伝播の Time Reversal による組織弾性イメージングシステム

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1. Introduction

Most diseases like chronic liver disease and cancer cause to change of tissue mechanical properties described by elasticity [1]. By visualizing these changes, we can diagnose disease early and the grade of disease. Shear wave elastography is one of methods of imaging tissue elasticity, and using the speed of shear wave generated by the acoustic radiation force impulse [2]. Conventional shear wave imaging uses time-of-flight method, however, it causes artifact by reflection and refraction of shear wave. In this study, we propose the tissue elasticity imaging using time reversal, which extracts the component of shear wave from the low-frequency vibration.

2. Method

We used ultrasonic echo to observe particle velocity caused by shear wave propagation for shear wave speed estimation. Then we conducted Fourier transform for an analysis of frequency component. Let $\Psi_z(x,z,t)$ be the displacement at position (x, z) at Tine t, and $\varphi_z(x,z,f)$ be the Fourier transformed value measured at the point $\varphi_z(x,z,t)$.

$$\varphi_z(x,z,f) = F[\Psi_z(x,z,t)], \quad (1)$$

where F denotes Fourier transform. After that we use whiting and gate function (2), (3) to improve signal-to-noise ratio.

$$\widetilde{\varphi_z}(x,z,f) = \begin{cases} \varphi_z(x,z,f)/\sqrt{P(x,z,f)} & (f_1 < f < f_2) \\ 0 & (otherwise) \end{cases} \quad (2)$$

$$\widetilde{\Psi_z}(x,z,t) = F^{-1}[\widetilde{\varphi_z}(x,z,f)] \quad (3)$$

Let $\widetilde{\varphi_z}(x,z,f)$, $\widetilde{\Psi_z}(x,z,t)$ be Fourier transform and displacement of z component respectively. We have selected $f_1 =$ 100 Hz and $f_2 =$ 200 Hz. In this band width, maximum frequency f_2 has given the most significant influence of refocusing the shear wave [3], [4]. The cross-correlation $C(x_0,x,z;\tau)$ processed between two points (x_0,z) and (x,z) represents the spatio-temporal coherence of the noise-induced displacement field, as in

$$C(x_0,x,z;\tau) = \int_{-\infty}^{+\infty} \widetilde{\varphi_z}(x_0,z,t) \cdot \widetilde{\varphi_z}(x,z,t+\tau)dt \quad (4)$$

Correlation is almost equal processing to time reversal methods, and it can converge shear wave hypothetically. The correlation map indicates shear wave propagation, and the -6dB focal width close to the half wavelength $\lambda/2$. This theoretical limit is known as the Rayleigh criterion [5]. The shear wave speed was deduced from estimation of the wavelength and frequency, through the relationship $c_s = f\lambda$. According to elasticity theory, the speed is the key parameter, because the shear wave speed c_s is related to the shear elasticity μ and Young's modulus E, according to: $c_s^2 = \mu/\rho \approx E/3\rho$. Therefore we can find the shear elasticity from -6dB focal width.

3. Experiment

The experimental setup is shown in **Fig. 1**. The sample used in this study is the inclusion phantom (inclusion: 80 kPa, background: 10 kPa).

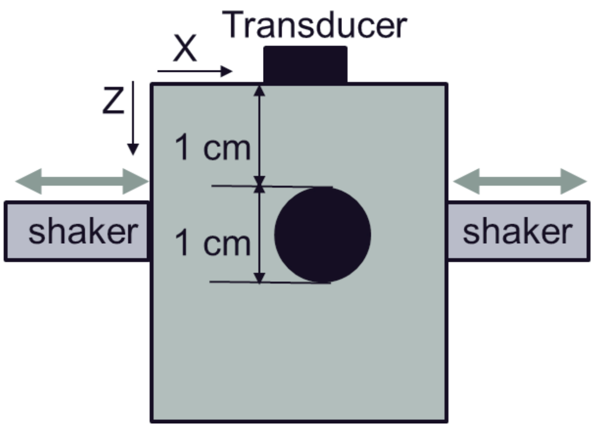


Fig. 1 Experimental setup for shear wave Elastography. A shaker located at side of the phantom creates a wave field inside the phantom.

In this study we use a mechanical vibrator (smartphone) to generate shear wave into the phantom, which locates at side of the phantom. A 7.5-MHz central frequency ultrasonic transducer is employed to record B-mode with in the media. The excitation has been done each side by turns for 40 times. The total observation time is 8 second.

4. Results

The cross-like shape represents converging field (t < 0) that focuses at t = 0 and then diverges (t > 0) (Fig. 2). The -6 dB focal width directly indicates a half wavelength of shear wave.

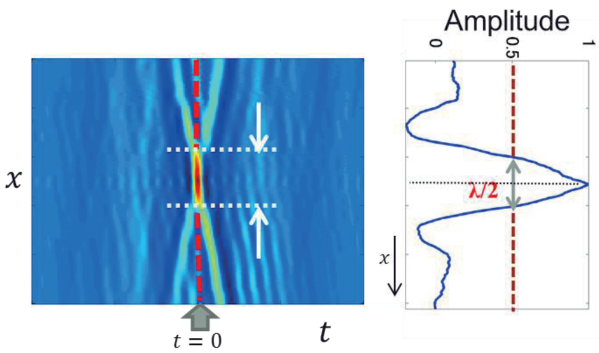
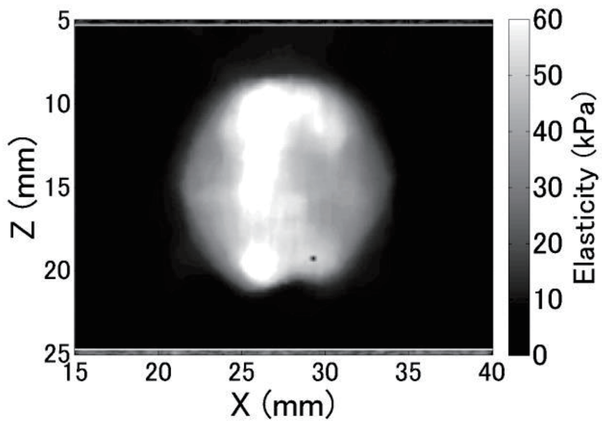


Fig. 2 (a) Spatial and temporal focusing of the correlation field using (4), and spatial focusing at Time $t = 0$.

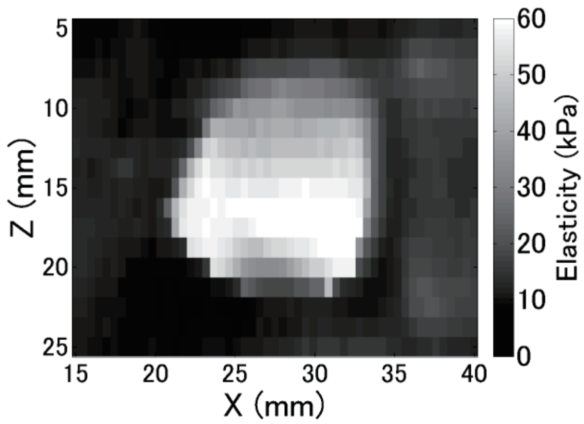
We compared the performance of our method with ultrasonic imaging system which use acoustic radiation force impulse (Aixplorer SWE: ShearWave™ Elastography) as the reference method. For the SWE, shear elasticity was 30.0±3.8 kPa and 10.4±0.9 kPa for the inclusion and background respectively (Fig. 3(a)). For our method, shear elasticity was 55.8±8.6 kPa and 9.9±2.1 kPa for the inclusion and background respectively (Fig. 3(b)). the inclusion was clearly visible and the obtained shear elasticity values were more close to nominal value (inclusion: 80kPa, background: 10kPa) than SWE.

4. Conclusion

We tried to measure elasticity of phantom by time reversal process using mechanical vibration. In proposal method, we can reconstruct the shear elasticity map and provide good contrast between the inclusion and background without artifats. Our method ignores the dispersive effects of shear wave due to viscosity, it may result in a biased estimate of the elasticity. Therefore, we will try to consider its effect by estimation of viscosity in the future.



(a)



(b)

Fig. 3 2-D shear elasticity maps of inclusion phantom with (a) SWE and (b) our methods

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References

1. A. Samani, et al.: Med. & Biol., **52**(2007)1565-1576.
2. H. Zhao, et al.: IUS, IEEE International, (2013)1256 – 1259.
3. T. Gallot, et al. IEEE Trans. Ultrason. Ferroelectr. Freq. Control, **58** (2011)1122-1126.
4. Keisuke Ogo, et al. Proc. of 2nd meeting of Photoacoustic Imaging, JSUM (2014) 12-16.
5. D. Cassereau, et al. IEEE Trans. Ultrason. Ferroelectr. Freq. Control, **39** (1992)579-592.