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Accuracy Improvement in Measurement of Arterial Wall Elasticity by Applying Pulse Inversion to Phased Tracking Method

パルスインバージョンを用いた位相差トラッキング法による血管壁弾性率測定の精度向上

Yukiya Miyachi[1,2†], Mototaka Arakawa[2,3] and Hiroshi Kanai[3,2]
([1]Medical Systems R&D Center, FUJIFILM Corp.; [2]Graduate School of Biomed. Eng., Tohoku Univ.; [3]Graduate School of Eng., Tohoku Univ.)
宮地幸哉 [1,2†], 荒川元孝 [2,3], 金井　浩 [3,2]
([1] 富士フイルム メディカルシステム開発センター; [2] 東北大院 医工; [3] 東北大院 工)

1. Introduction

Measurement of arterial wall elasticity is useful for diagnosing between the elasticity of normal arterial walls and those affected by atherosclerosis[1)]. In series of studies on noninvasive assessment of the regional elasticity of the arterial wall, the elasticity is measured from the small change in thickness due to the heartbeat and the blood pressure by the phased tracking method[2)]. To track the movement of the carotid arterial wall, a high frame rate, at least over 100Hz, is necessary. These methods can evaluate the elasticity precisely if images are clear. Unfortunately, most images in a clinical situation contain various type of noise such as multiple reflection noise, making it difficult to evaluate the elasticity precisely.

To suppress the multiple reflection noise, tissue harmonic imaging is widely used in carotid artery exams. The pulse inversion (PI) method is one of the tissue harmonic imaging techniques and preferred to obtain more broadband images[3)].

In the present study, modified phased tracking method using PI method is examined with the aim of reducing the influence of multiple reflection noise on the estimation of elasticity. The improvement of accuracy by the proposed method is validated by the silicone rubber tube phantom.

2. Method

2.1 Phased-tracking method

For estimation of the displacement, using the quadrature demodulated signal, the phase shift $\Delta\Psi_i(t;\, l)$ between echoes in two consecutive frames along the l-th ultrasonic beam is obtained from the complex cross-correlation function. The object position $x_i(t;\, l)$ is tracked by integration of the average velocity, $v_i(t + T_\mathrm{r}/2;\, l)$, as follows:

$$x_i(t+T_\mathrm{r};\, l) = x_i(t;\, l) + v_i(t+T_\mathrm{r}/2;\, l) \times T_r$$
$$= x_i(t;\, l) + (c_0/2\omega_0)\Delta\Psi_i(t;\, l) \times T_\mathrm{r}. \quad (1)$$

where ω_0, c_0 and T_r are the center angular frequency of the ultrasonic pulse, the speed of sound, and the pulse repetition interval respectively. The small change in thickness is calculated by the positions of inner and outer tube surface. The elasticity is estimated from the change in thickness and the internal pressure.

2.2 PI method

The PI method transmits two pulses with opposite polarity and then sums their echoes. When summed, the fundamental components cancel while the harmonics double. However, because two pulses are needed to be transmitted to create a single harmonic echo, the frame rate of the PI methods is reduced. To avoid aliasing of phase shifts of harmonic signals, the fundamental components, subtracted of the two pulses, are used to correct the phase shifts of the harmonic signals. **Figure 1** shows an outline of the PI method in this study.

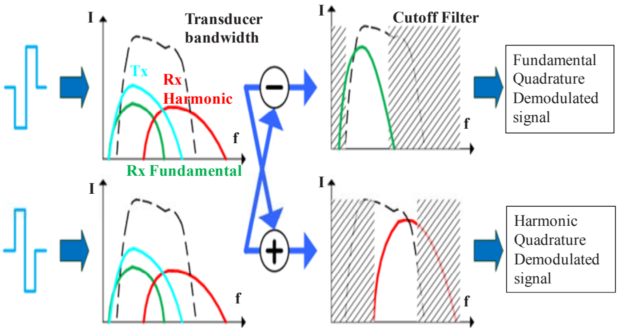

Fig. 1. Outline of the PI method.

The phase shift of harmonic quadrature demodulated signal θ_harm is roughly equal to $(f_\mathrm{harm} / f_\mathrm{fund}) \times \theta_\mathrm{fund}$, where f_harm, f_fund and θ_fund are the harmonic detection center frequency, the fundamental detection center frequency and the phase shift of fundamental quadrature demodulated signal, respectively. To correct aliasing of phase shifts of harmonic signals, firstly aliasing number candidate is evaluated by

$$\pi \times \left(\frac{f_\mathrm{fund}}{f_\mathrm{harm}}\right) \times (2n+1) + W > \theta_\mathrm{fund} > \pi \times \left(\frac{f_\mathrm{fund}}{f_\mathrm{harm}}\right) \times (2n-1) - W, \quad (2)$$

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†yukiya.miyachi@fujifilm.com

where W is empirical constant which is sufficiently smaller than $\pi/2$. Secondly, aliasing number n is determined by minimizing the following $e(n)$.

$$e(n)=\left|\theta_{\mathrm{harm}}+2\pi n-\theta_{\mathrm{fund}}\times\left(\frac{f_{\mathrm{harm}}}{f_{\mathrm{fund}}}\right)\right|. \quad (3)$$

Lastly, corrected θ_{harm} is expressed by $\theta_{\mathrm{harm}}+2\pi n$. The phase shifts of harmonic, fundamental and corrected harmonic are shown in **Fig. 2**. The corrected phase shift is applied to phased-tracking method.

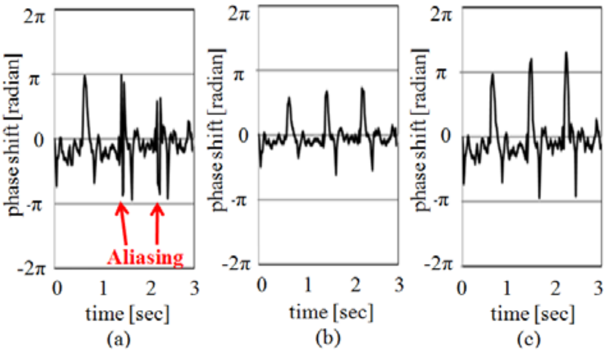

Fig. 2. Phase shift. (a) Harmonic. (b) Fundamental. (c) Corrected Harmonic.

3. Experimental Setting and Results

We prepared a phantom mimicking the arterial wall made of silicone rubber tube pulsated by a stepping motor pump. The thickness of the silicone rubber tube is 1.1 mm and the inner diameter is 8 mm, which are similar to those of the carotid artery. To evaluate the influence of multiple reflection noise on posterior wall between anterior wall and transducer, the distance from transducer to the tube is controlled, as shown in **Fig. 3**.

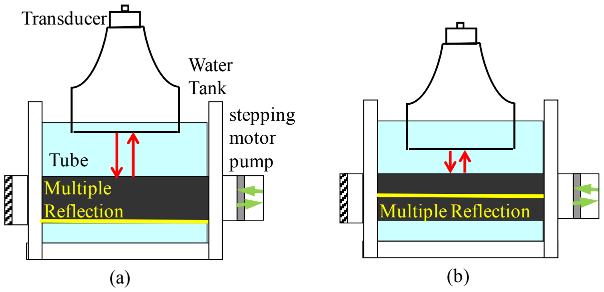

Fig. 3. Arterial wall mimicking phantom. (a) Multiple reflection noise on the posterior wall. (b) Multiple reflection noise inside the tube.

Experiments were conducted using ultrasonic equipment, FUJIFILM FC1 and linear transducer. Change in thickness is compared in Fundamental and PI mode experiments. Ultrasound scanning conditions are summarized in **Table. 1**.

Figures 4(a)-4(d) show M-mode images with tracking results with respect to the posterior wall overlaid and the change in thickness of posterior wall in the fundamental and PI mode experiments in the condition that multiple reflection noise is on posterior wall.

Mode	Transmitting Frequency	Detection Frequency	Frame Rate
Fundamental	9 MHz	9 MHz	200 Hz
PI	4.5 MHz	9/4.5 MHz	100 Hz

Table 1. Scanning conditions.

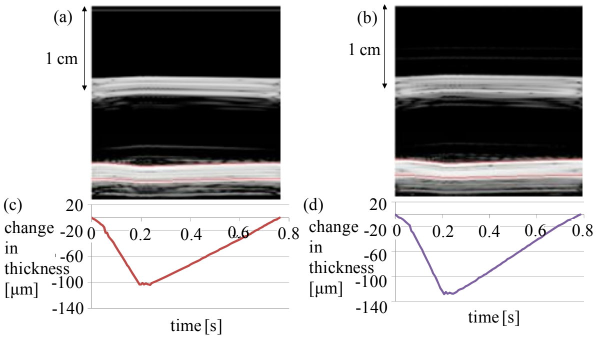

Fig. 4. (a) M-mode (Fundamental). (b) M-mode (PI). (c) Change in thickness (Fundamental). (d) Change in thickness (PI).

Multiple reflection noise was less in PI mode as shown in **Fig. 4(b)**. The maximum change in thickness of fundamental mode was -104 μm and that of PI mode was -129 μm. The maximum change of thickness differences between multiple reflection noise positions are summarized in **Table. 2**.

Noise position	Fundamental	PI
On posterior wall	-104 μm	-129 μm
Inside tube	-124 μm	-124 μm

Table 2. Comparison of maximum change in thickness.

It is confirmed that the influence from multiple reflection noise was less in PI mode. The elasticity was calculated from these results and elasticity differences from “without multiple reflection noise” were 20% for fundamental mode, -4% for PI mode, respectively.

4. Conclusion

We proposed a new method to improve the measurement of elasticity by applying PI method to phased-tracking method. This method has a potential to be useful for precise elasticity imaging.

References

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