3P5-20

Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 547-548
3-5 December, 2014

A Method to Reduce the Influence of Reflected Shear Waves on Shear Velocity Measurement

Zhen Qu[1] and Yuu Ono[1†] ([1]Dept. of Systems & Computer Eng., Carleton Univ.)

1. Introduction

Viscoelasticity could be used in medical diagnosis to evaluate tissue health based on stiffness variation. Several ultrasound based methods to determine the viscoelasticity have been developed using a shear wave (SW) induced in human soft tissues.[1-3] In these methods, the SW velocity is estimated by tracking the SW propagation using ultrasound to determine the viscoelasticity.[4]

However, when the specimen is relatively small, the SW induced by a continuous vibration source may be reflected at tissue interfaces. Therefore, the observed SW could be interference waves composed of forward and backward SWs. This interference may affect the measurement accuracy of the SW velocity.

In the conventional B-mode ultrasound measurement there is a scanning time delay between the sequential A-mode measurements. In this study, we propose a method to reduce the influence of reflected SW on measurement accuracy of SW velocity using the spatial frequency shift from the scanning time delay in B-mode measurement.

2. Methodology

A measurement model of SW propagation is depicted in **Fig. 1**. An ultrasound transducer array is attached on top of the specimen. Thus, in each A-mode measurement ultrasound signals are acquired along the depth (x-direction) of the subject.

A continuous SW vibration source is placed in contact on one side of the subject. Therefore, the SW propagated along the specimen length (z-direction) parallel to the scanning direction in the B-mode measurement. The SWs are assumed to be plane waves in this study. The induced SW (forward wave) may be reflected from the opposite end of the subject, resulting in a backward SW which could interfere with the forward SW as shown in **Fig.1**.

The tissue displacement (magnitude of the SW) along the x-direction due to the SW propagation can be estimated by analyzing the phase variation of acquired ultrasound radio-frequency (rf) signals in each A-mode measurement.[6] The phase of the rf signals is obtained by a quadrature detection technique.[7]

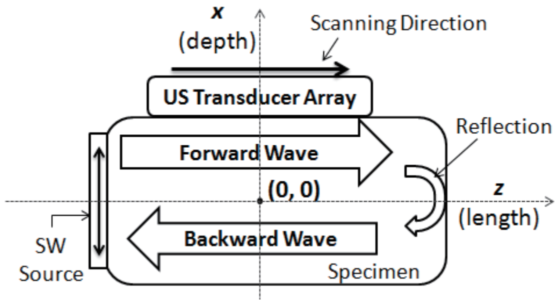

Fig. 1 Measurement model of SW propagation.

The displacement of the observed SW, $V(t, z)$, is expressed by a summation of forward, $V_F(t, z)$, and backward, $V_B(t, z)$, SWs as follow.

$$V(t,z) = V_F(t,z) + V_B(t,z), \quad (1)$$

where t is the time. By including the scanning time delay in the B-mode measurement, the $V_F(t, z)$ and $V_B(t, z)$ can be represented as follows.

$$V_F(t,z) = A_F \cos\left[\omega_S\left(t + \Delta t\frac{z}{\Delta z}\right) - k_S z + \varphi_F\right] \quad (2)$$

$$= A_F \cos\left[\omega_S t - \left(k_S - \frac{\omega_S \Delta t}{\Delta z}\right) z + \varphi_F\right], \quad (3)$$

$$V_B(t,z) = A_B \cos\left[\omega_S\left(t + \Delta t\frac{z}{\Delta z}\right) + k_S z + \varphi_B\right] \quad (4)$$

$$= A_B \cos\left[\omega_S t + \left(k_S + \frac{\omega_S \Delta t}{\Delta z}\right) z + \varphi_B\right], \quad (5)$$

where A_F and A_B are the SW amplitude, and φ_F and φ_B are the initial phase, of the forward and backward SWs, respectively. ω_S ($= 2\pi f_S$) is the SW angular frequency, and k_S ($= \omega_S/v_S$) is the SW wavenumber where v_S is the SW velocity. Δt and Δz are the temporal and spatial interval, respectively, between two consecutive A-mode measurements.

Due to the scanning time delay in the B-mode measurement, the time of each A-mode measurement at the location z has a delay, given by $\Delta t(z/\Delta z)$, from the first A-mode measurement, as seen in (2) and (4). Thus, it resulted in the negative and positive spatial frequency shift of $\omega_S\Delta t/\Delta z$ for V_F and V_B, respectively, as seen in (3) and (5).

Therefore, $V_F(t, z)$ can be retrieved from the measured $V(t, z)$ using a spatial frequency filter. An out-of-phase signal with 90° phase shift with respect to z is obtained from a Hilbert transform ($\mathcal{H}_z$) and used to create an analytic complex signal $V_F^*(t, z)$ as follow.

$$V_F^*(t,z) = V_F(t,z) + i\mathcal{H}_z\{V_F(t,z)\}. \quad (6)$$

Finally, v_S at each z is estimated by taking the spatial derivative of the phase of V_F* with respect to z as follow.

$$v_S(z) = \frac{1}{\frac{\Delta t}{\Delta z} - \frac{1}{\omega_S} \cdot \frac{\partial[\angle V_F^*(t,z)]}{\partial z}}. \quad (7)$$

3. Experiment

A soft tissue mimicking phantom was constructed using agar and water to verify the proposed method for the SW velocity measurement. The phantom had a cubic shape with a side length of 50 mm. Fine graphite powders were dispersed in the phantom as ultrasound scatterers. A square Plexiglas plate (50 mm x 50 mm) connected to a sound speaker was used as the SW vibration source. The plate vibrated continuously in x-direction during measurements producing a sinusoidal SW at 500 Hz.

An ultrasound medical imaging system (Model Picus from ESAOTE Europe, Maastricht, Netherlands) with a linear array probe (L10-5) was used in the experiment. The B-mode measurement had a measurement area of 35 mm in depth (x-direction) and 40 mm in length (z-direction).

The observed SW displacements, V, are shown in **Fig. 2(a)**. The displacement at x = 0 is also presented in **Fig. 2(b)**, in which the interference due to the reflected SW is clearly observed. **Fig. 2(c)** presents the spatial frequency spectrum of the measured SW displacement in **Fig. 2(b)**. In **Fig. 2(c)**, the two frequency components corresponding to the V_F and V_B are seen. The V_B was removed from V by the spatial low pass filter and the results are shown in **Figs. 2(d)-(f)**.

Fig. 3 shows the SW velocities obtained from the SW displacement in **Fig. 2(d)** using (7). The mean value of the SW velocities in the entire B-mode measurement is 5.6 m/s with its standard deviation of 1.1 m/s. It is noted that greater deviations are observed at the edges of the measurement area. This is likely due to the phase estimation error from the analytic signal calculated by the Hilbert transform.

4. Summary

A method to reduce the error from reflected SW to measurement accuracy of SW velocity was proposed in this study. The scanning time delay in B-mode measurement causes a spatial frequency shift between the forward and backward SWs measured. Therefore, these SWs could be separated using a spatial frequency filter. The proposed method was verified using a soft tissue mimicking phantom. The reflected SW was filtered out from the observed SW and the SW velocities were determined.

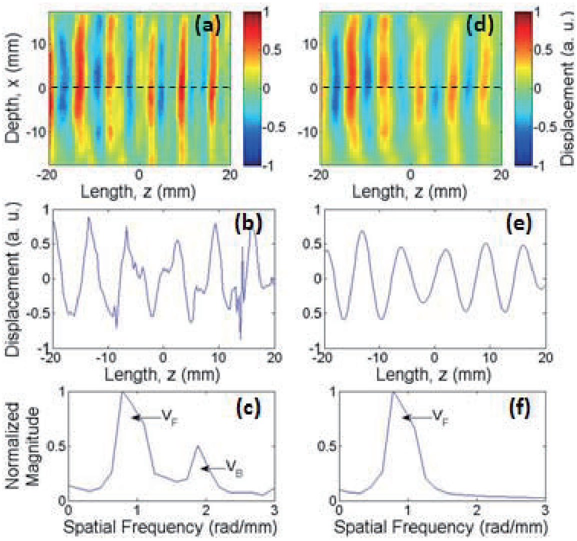

Fig. 2 Observed SW displacement at (a) entire area and (b) x = 0, and (c) spatial frequency of the displacement in (b). Filtered SW displacement at (d) entire area and (e) x = 0, and (f) spatial frequency of the displacement in (e).

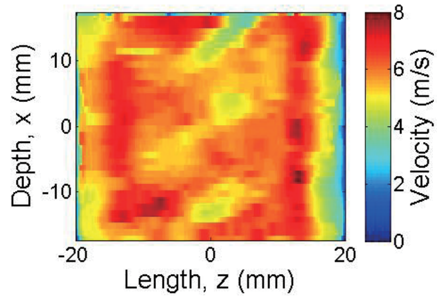

Fig. 3 Measured SW velocities in the phantom sample.

Acknowledgment

The authors are thankful to Dr. A. Adler for allowing us to use the ultrasound imaging system. This work was supported by Natural Sciences and Engineering Research Council of Canada.

References

1. Y. Yamakoshi, J. Sato, and T. Sato: IEEE Trans. Ultrason. Ferroelect. Freq. Contr. **37** (1990) 45.
2. Z. Wu, L. S. Taylor, D. J. Rubens, and K. J. Parker: Phys. Med. Biol. **49** (2004) 911.
3. S. Chen, M. Fatemi, and J. F. Greenleaf: J. Acoust. Soc. Am. **115** (2004) 2781.
4. H. L. Oestreicher: J. Acoust. Soc. Am. **23** (1951) 707.
5. L. Sandrin, M. Tanter, S. Catheline, and M. Fink: IEEE Trans. Ultrason. Ferroelect. Freq. Contr. **49** (2002) 426.
6. V. Dutt, R. R. Kinnick, and J. F. Greenleaf: IEEE Ultrasonic Symposium **2** (1996) 1185.
7. N. Feng, J. Zhang, and W. Wang: Ultrasonics **44** (2006) e47.