3P2-6

Study of non-contact measurement of sound speed in incline-sided phantom using pass-through airborne ultrasound
空中超音波による側面が傾斜したファントムの非接触音響特性計測手法の検討

Daisuke Hanawa‡, Shinnosuke Hirata, and Hiroyuki Hachiya (Tokyo Tech)
塙 大祐‡, 平田 慎之介, 蜂屋 弘之 (東工大)

1. Introduction

Bone assessment by quantitative ultrasound (QUS), measurement of ultrasonic propagation characteristics in cancellous bone, is one of the diagnosis methods of osteoporosis. In typical QUS devices, ultrasonic transducers are brought into contact with tissue surfaces through an ultrasonic gel to effectively propagate ultrasound. We have proposed a non-contact measurement of propagation characteristics using airborne ultrasound passed through a tissue[1,2]. In this paper, the speed of sound (SOS) in the phantom, which mimics a heel shape, is estimated by the proposed and typical method to evaluate the accuracy of the proposed method.

2. Measurement configuration

Due to the difference of specific acoustic impedance between air and phantom, reflection and strong attenuation occur at the boundary. Thus, we measured the shape of the side of phantom. Then, we inclined transducers in angles at which pass-through ultrasound can fully be received by the transducer. Moreover, pulse compression by an M-sequence is employed to improve the signal-to-noise ratio (SNR). Phantom which used in this experiment is shown in **Fig.1**. Phantom was made by dissolving agar in water so that mass ratio is controlled to be 2.5%, and cooled to harden.

In measurement of inclinations of surfaces of the phantom, the frequency of transmitted ultrasound was 166.7 kHz, which is approximately the central frequency of transducers. The M-sequence was a 8th-order sequence. The M-sequence modulated signal was generated in the function generator. Then, the signal was amplified to 150 Vpp and transmitted by transducer. The multiple reflections were received by microphone. The received signal was amplified by 20 dB. Then, the signal was recorded by the data logger of 14 bit. The sampling frequency in this system was 8 MHz. The received signal was correlated with the used M-sequence code.

In measurement of ultrasound passed through phantom, the M-sequence was a 17th-order sequence to improve the SNR even better. The received signal was amplified by 60 dB and passed through high-pass filter of 10 kHz.

Fig. 1 Phantom.

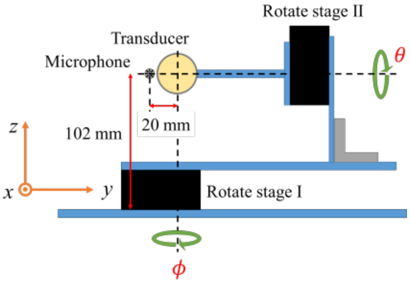

Fig. 2 Experimental setup.

3. Measurement of inclinations of surfaces of the phantom using pulse-echo method

When pulse wave is transmitted for surface of phantom, multiple reflections occur. Therefore, microphone is arranged at the side of transducer whose inclination can be controlled, as shown in **Fig.2**, and then we can obtain angle characteristics of multiple reflections. Transducers can be rotated in θ direction and φ direction. Let $\theta = 0^\circ$ and $\phi = 0^\circ$ if vibration surfaces coincides with yz plane. Due to previous work, multiple reflections are observed for the longest time if surface of transducer and that of phantom are parallel[3]. **Fig.3** shows multiple reflections when scanning left side of phantom along θ when $\varphi = 19.0^\circ$. Multiple reflections can be observed for the longest time around $\theta = 16^\circ$. Power of received signal after 1 ms at each angle is shown in **Fig.4**. Maximum power is observed when $\theta = 16.0^\circ$. Then, let angle at which power of received signal after 1 ms is the maximum be angle at which surface of transducer and surface of phantom are parallel. In actual experiment, to begin with, angle of transducers was visually adjusted so

---

‡E-mail address : hanawa@us.ctrl.titech.ac.jp

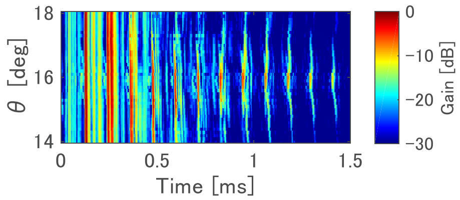

Fig. 3 Multiple reflections between phantom and transducer scanning along θ when $\varphi = 19.0°$.

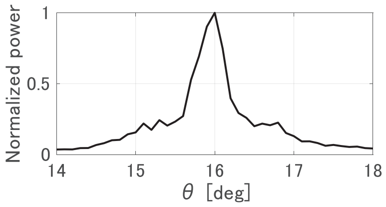

Fig. 4 Power of received signals after 1 ms.

that vibration surfaces parallelely faced the phantom. After that, scannings along φ direction and θ direction were alternately performed. Then, angle at which surface of transducer and that of phantom were parallel was found. We measured inclinations of surfaces of the phantom 30 times. Results of θ of both sides and the sum of φ assumes to be constant. However, those angles took values within the range of ±2°.

4. Experiment result

From the result of inclinations of surfaces of phantom as described in section 3, temperature during the experiment, and SOS in phantom which is assumed to be 1500 m/s, inclinations of transducers were adjusted. After that, we observed airborne ultrasound passed through phantom. Ultrasound was transmitted by left transducer, and received by right one. Received signal is illustrated in **Fig.5**. The transmission loss is approximately 61 dB. Let time of flight (TOF) of received signal illustrated in Fig.5(a) be t_1, one illustrated in Fig.5(b) be t_2. In addition, let distance between transducer for transmission and phantom be l_1, propagated distance in phantom be l_2, and distance between transducer for receiver and phantom be l_3 as shown in **Fig.6**. SOS in phantom is represented by formula 1.

$$v_{phantom} = \frac{l_2 v_{air}}{l-(l_1+l_3)-v_{air}(t_2-t_1)} \qquad (1)$$

$t_2 - t_1$ is obtained from the cross-correlation between two received signals. l_1 and l_3 are obtained from time interval of multiple reflections which occurs while measuring of inclinations of surfaces of the phantom. l_2 is obtained from geometric positional information such as inclinations and positions of transducers, l_1 and l_3. Then, **Fig.7**(a) shows histogram of the SOS. Average of SOS in phantom is 1522 m/s. Standard deviation is 18.3 m/s. To compare with this result, we calculated SOS in phantom by contact measurement. The phantom , the transducers, and the transmitted signal were the same as those in noncontact measurement. The received signal was passed through high-pass filter of 10 kHz. Then, Fig.7(b) shows histogram of the SOS. Average of SOS in phantom is 1526 m/s. Standard deviation is 10.0 m/s.

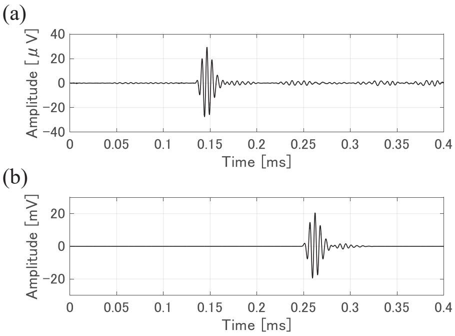

Fig. 5 Received signal passed through (a) heel when transducers are inclined, and (b) air when transducers are horizontal.

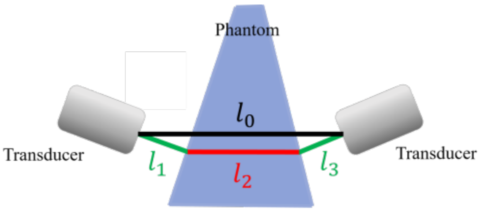

Fig. 6 Propagation path.

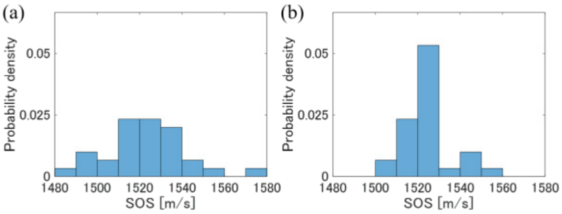

Fig. 7 Histogram of SOS in phantom in (a) non-contact measurement, (b) contact measurement.

5. Conclusion

In this paper, SOS in the phantom, which mimics a heel shape, is estimated by the proposed and typical method to evaluate the accuracy of the proposed method. Difference of average of SOS was approximately 4 m/s. Therefore, SOS in a phantom can be also estimated in the proposed method.

References

1. S. Hirata, et al.: Jpn. J. Appl. Phys., **53**, No. 7S, 07KC17, 2014.
2. S. Hirata, et al.: 2016 IEEE Int. Ultras. Symp., Tours, France, 2016.
3. D.Hanawa, et al.: Acoust. Soc. Jpn. 2016 autumn meeting, pp. 1263-1264, Sep. 2016.