Study of non-contact measurement of sound speed in incline-sided phantom using pass-through airborne ultrasound

Daisuke Hanawa¹, Shinnosuke Hirata, and Hiroyuki Hachiya (Tokyo Tech)

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 tissue¹,². 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

³E-mail address : hanawa@us.ctrl.titech.ac.jp

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 θ = 0° and φ = 0° 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 φ = 19.0°. Multiple reflections can be observed for the longest time around θ = 16°. Power of received signal after 1 ms at each angle is shown in Fig.4. Maximum power is observed when θ = 16.0°. 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

Fig. 1 Phantom.

Fig. 2 Experimental setup.

Fig. 3 Measurement results when the subject was

Fig. 4

Fig. 5 Measurement results when the subject was

Fig. 6

References


that vibration surfaces parallely faced the phantom. After that, scannings along $\phi$ direction and $\theta$ 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 $\theta$ of both sides and the sum of $\phi$ assumes to be constant. However, those angles took values within the range of $\pm 2^\circ$.

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.

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

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