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Non-contact measurement of acoustic characteristics in tissues using a pass-through airborne ultrasonic wave for ultrasonic bone assessment

超音波骨評価を目的とした透過した空中超音波による生体組織音響特性の非接触計測

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1. Introduction

Elastic properties or tissue structure can be quantitatively evaluated by measuring velocities or attenuations of ultrasonic waves, which propagate in the tissue. Ultrasonic bone assessment is studied and applied in clinical practice because it is minimally invasive and free from X-ray exposure[1)]. In the typical method of ultrasonic bone assessment, the propagation path of the ultrasonic wave has to be filled with mediums, whose acoustic characteristics are similar to tissues. Therefore, transducers are brought into contact with examined regions through an ultrasonic coupling gel.

Non-contact bone assessment in a heel using an airborne ultrasonic wave has been proposed to improve repetitively and continuity of ultrasonic bone assessment. In the proposed method, a calcaneus is evaluated from the pass-through airborne ultrasonic wave in the heel. However, the pass-through wave is extremely attenuated by boundary reflections, which are between air, soft tissue, solid bone and cancellous bone. Therefore, S/N improvement by pulse compression using high-order M-sequence has been employed to detect pass-through waves[2)]. However, evaluation of the calcaneus by the propagation velocity is difficult, because the TOF of the pass-through wave cannot be determined. In this report, TOF determination of the pass-through wave and measurement of the propagation velocity in the ultrasonic phantom are described.

2. Bone assessment of a calcaneus using airborne ultrasonic waves

In the proposed bone assessment of a calcaneus, an airborne ultrasonic wave, which is modulated by 18th-order M-sequence, is transmitted from a transducer to the inner side of the heel. Then, the pass-through wave in the heel is received by another transducer of the outer side.

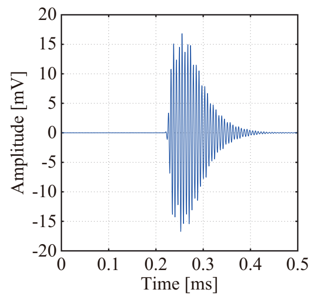

Fig. 1 The cross-correlation function of the received signal when there is no object between the transducers.

The frequency of the transmitted wave is 166.7 kHz, which is around of the resonance frequency of transducers. To detect the pass-through wave, The S/N of the received signal is improved by cross correlation with a reference signal, which is corresponds the transmitted signal. The time of flight (TOF) of the pass-through wave is determined to estimate the propagation velocity in the heel.

When a TOF of a received wave is determined, a pulse wave or a short-length wave is generally transmitted in 1 digit of M-sequence modulated signal. Therefore, 2 sine waves are assigned in 1 digit. If the bandwidth is enough, the received wave in the cross-correlation function also shows 2 sine waves. However, the received wave is broadened as illustrated in **Fig. 1**, because the bandwidth of transducers is very narrow. Therefore, the TOF of the received wave has to be determined from the beginning of the wave.

3. Identification of the beginning of the pass-through wave

When there is an object between the transducers, the S/N of the received signal is extremely degraded. Therefore, identification of the beginning for TOF determination is difficult. To eliminate the ringing by transducers of the received wave, 1 sine wave and 1 inverse sine wave are assigned in 1 digit instead of 2 sine waves as

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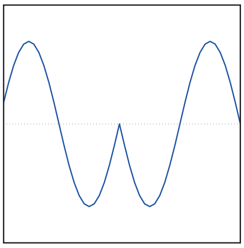

Fig. 2 1 sine wave and 1 inverse sine wave, which are assigned in 1 digit of M-sequence-modulated signal.

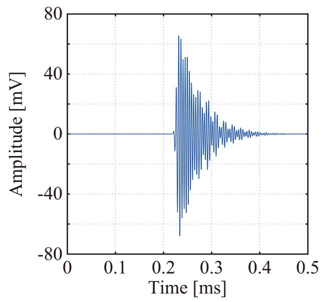

Fig. 3 In case 1 sine wave and 1 inverse sine wave are assigned in 1 digit, the cross-correlation function of the received signal.

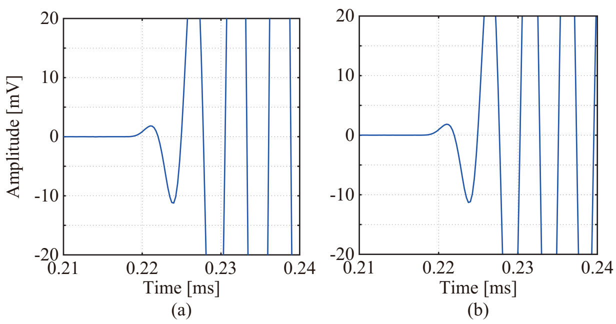

Fig. 4 Close-up views of beginnings of received signals, (a) 2 sine waves are assigned, (b) 1 sine wave and 1 inverse sine wave are assigned.

illustrated in **Fig. 2**. By altering the transmitted signal, the received wave in the cross-correlation function is shortened as illustrated in **Fig. 3**. The ringing is suppressed to 40 % of Fig. 1. However, the amplitudes of beginnings of received waves are equivalent as illustrated in **Fig. 4**. Therefore, the resolution of an oscilloscope about the beginning is improved.

4. Measurement of the propagation velocity in the ultrasonic phantom

The propagation velocity in the ultrasonic phantom was measured by the pass-through airborne ultrasonic wave. The width of the phantom was 71 mm. The nominal propagation velocity of the phantom was 1451 m/s in 23 °C. In the experiments, room air temperature and phantom

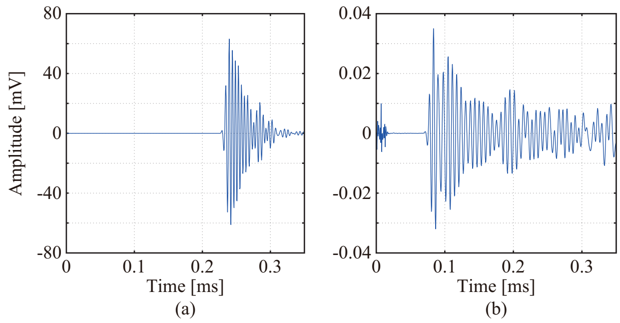

Fig. 5 The cross-correlation function of the received signal, (a) when there is no object between the transducers, (b) when there is the ultrasonic phantom between the transducers.

temperature were approximately 23 °C. To improve the S/N of the received signal, the order of M-sequence was increased to 19th. The received signal of the transducer was amplified by 60 dB and passed through a band pass filter from 20 kHz to 800 kHz. Then, the signal was recorded to PC by 2 MHz sampling and processed in MATLAB

The propagated wave, when there is no object between the transducers, and the pass-through wave in the phantom were detected as illustrated in **Fig. 5**. Furthermore, TOFs could be determined from beginnings of each wave. The propagation velocity in the phantom was estimated in 10 times experiments. The average and standard deviation of estimated propagation velocities were 1452 m/s and 4.2 m/s.

5. Conclusion

Non-contact bone assessment in a heel using an airborne ultrasonic wave has been proposed. By elimination of the ringing by transducers of the received wave and pulse compression using 19th-order M-sequence, the TOF of the pass-through wave in the ultrasonic phantom could be determined from the beginning of the wave. Therefore, the propagation velocity in the phantom could be estimated with high accuracy.

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References

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