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# Experimental Study on Instantaneous Frequency Analysis of Ultrasonic Propagated in Cancellous Bone
海綿骨伝搬超音波波形の瞬時周波数解析

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## 1. Introduction

An ultrasound pulse wave propagating through cancellous bone separates into two waves, called as “fast and slow waves”. Hosokawa *et al*. pointed that the center frequency of fast wave became lower than that of the incident wave[1]. Cardoso *et al*. also showed that short-time Fourier transform visually demonstrated the decrease of fast wave frequency[2].
Hasegawa *et al*. successfully separated two waves with Wavelet transform[3]. As a result, they showed that lower frequency component including fast wave lasted long. Their result suggested that fast wave was affected by multiple scattering in trabeculae.
Nagatani *et al*. examined the property of the attenuation of fast wave, suggesting the possibility that multipath in medium had important influence on the decreasing property of fast wave frequency[4]. If the frequency of fast wave can be measured quantitatively, surmise of the network topology of specimen may be realized.
Therefore, this study examines the phenomena of ultrasound in cancellous bone using instantaneous frequency technique.

## 2. Theory

In this experiment, a pair of short waveforms that had phase difference of 90° was used as incident signals. These two signals were regarded as the real and imaginary part of a complex signal:

$$F(t) = G(t) + iH(t) \ , \qquad (1)$$

where $F(t)$ is an analytic signal, and $G(t)$ and $H(t)$ are the real and imaginary part of the analystic signal, respectively. Here, the instantaneous phase of $F(t)$ could be obtained by the following expression:

$$\omega(t) = \tan^{-1}\frac{H(t)}{G(t)} \ . \qquad (2)$$

Then, the instantaneous frequency of the analytic signal was derived as the time derivative of the instantaneous phase. Although this method is equivalent to the Hilbert transform of one incident signal, the use of two signals is expected to have an advantage in robustness against background noise.

## 3. Measurement System

As a specimen, bovine cancellus bone, whose size was 35.5 mm wide, 35.5 mm high and 8.0 mm deep, was used. **Figure 1** shows the measurement system. The specimen was immersed in degassed water. **Figures 2** and **3** show the initial waveforms at 1 MHz. A single cycle wave or sinusoidal waves with Gaussian window (Gabor waveforms) were transmitted by PVDF transducer. The ultrasound passed through the specimen was received by PVDF transducer.

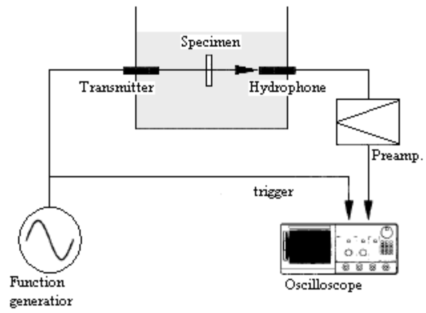


Fig. 1 Measurement System.

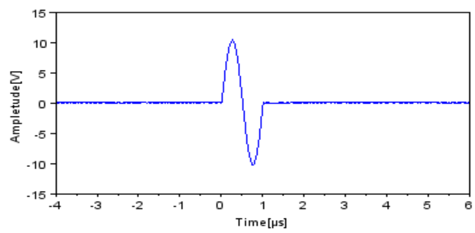


Fig. 2 Initial waveform of single Sinusoidal.

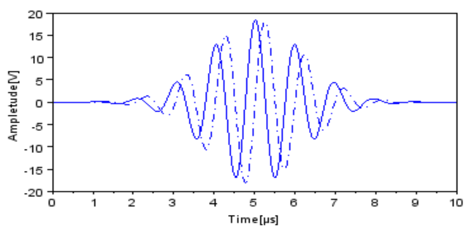


Fig. 3 Initial waveforms of Gaussian Pulse.

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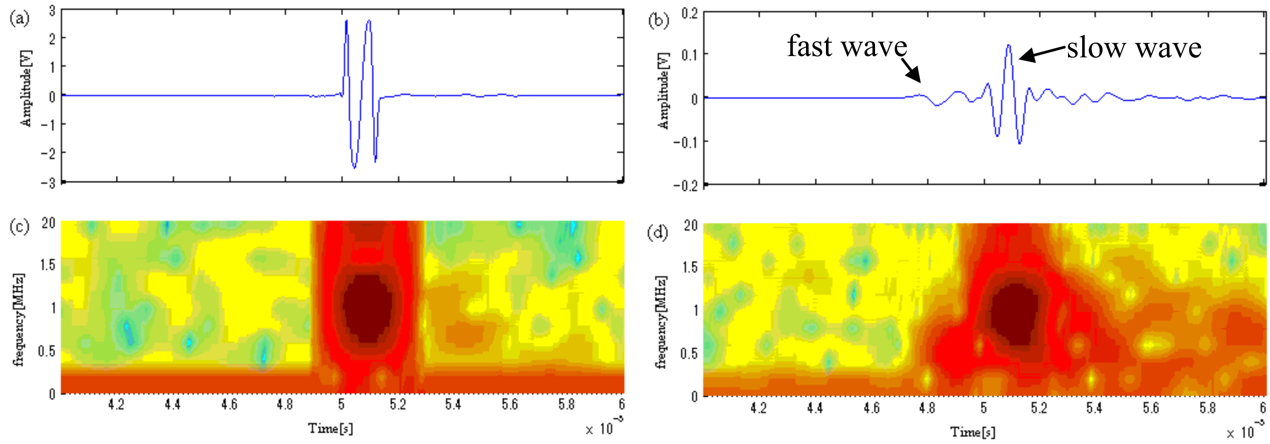


Fig. 4 Results of pulse-wave technique (pulse wave).
(a)Observed waveform without specimen (b)Observed waveform with specimen
(c)Spectrogram of (a) (d)Spectrogram of (b)

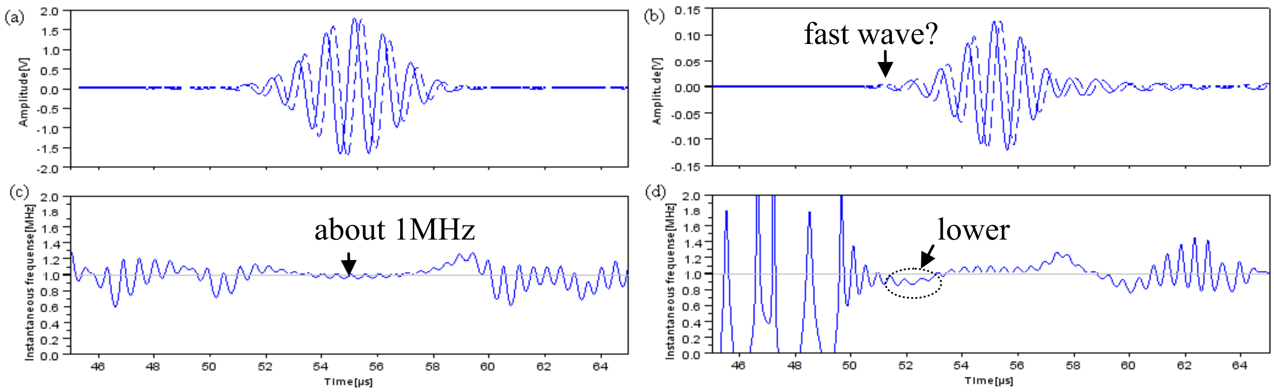


Fig. 5 Results of Gabor waveforms.
(a)Observed waveform without specimen (b)Observed waveform with specimen
(c)Instantaneous frequency of (a) (d)Instantaneous frequency of (b)

## 3. Results and Discussion

In order to reduce the noise in the received waves, a digital filter whose bandwidth was 0.5 MHz~1.4 MHz was used. **Figures 4** and **5** show the results. Figures 4(a)(b) and 5(a)(b) show the waveforms and 4(c)(d) and 5(c)(d) show the spectrograms and instantaneous frequency respectively. The two-wave phenomenon was clearly seen in Fig.4(b).

Both of the center frequency and the instantaneous frequency of the waves passed through only water were about 1 MHz (Fig.4(c) and Fig.5(c)), which is same as the transmitted waves.

In contrast, when the wave propagated in cancellous bone, the frequency of fast wave (Fig.4(d)) and the instantaneous frequency of faster part (Fig.5(d)) were lower than 1 MHz. Although it is difficult to determine the center frequency of the fast wave in the spectrogram using single-pulse method (Fig.4(d)), the instantaneous frequency could be investigated quantitatively (0.83 MHz at about 52 μs in Fig.5(d)). This behavior agrees with conventional thought that the frequency of fast wave decreases caused by the multi-path effect to medium.

## 4. Conclusion

In this study, the frequency decreasement of fast wave in cancellous bone was confirmed by experimental measurement using instantaneous frequency technique. Since this technique is sensitive to the noise in the signal, robuster analysis method is required for the practical usage.

## Reference

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