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Measurement of ultrasonic transmission attenuation characteristics of canvas fabric

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1. Introduction

Acoustic sensing in air has potential applications for obtaining various types of information about the surrounding object such as its position, shape, material and movement [1–10]. We reported results of the position detection of small objects with a size comparable to the signal wavelength, using an M-sequence-modulated signal [11,12]. We have also examined a noncontact measurement method for vital information, such as breathing and heartbeat, by measuring human body surface movement using airborne ultrasound [13]. There is a growing need for noncontact medical monitoring methods for individuals at home without their being aware of the monitoring and without any constraint [14,15]. The airborne ultrasound technique has advantages of requiring only small devices and less electromagnetic interference. However, measurement of the movements of the human body surface covered with clothes is difficult because of a large transmission attenuation by the clothes. We have already attempted the detection of small movements of an object behind fabric [16]. To design a measurement system for movements underneath clothes worn, it is important to obtain transmission characteristics of a clothing material. Many studies of the acoustic properties of fabrics have been carried out presented at audible frequencies for sound environment control [17]. However, the acoustic properties of fabrics in the ultrasound range have not been sufficiently examined. In this paper, we present the acoustic transmission attenuation characteristics of canvas fabric as an example of a clothing material using an ultrasound at frequencies over 20 kHz.

2. Materials and method

To obtain the ultrasonic transmission characteristics of canvas fabric, acoustic signal passing through canvas fabric was observed. The measurement configuration is shown in Fig. 1. A speaker (Pioneer PT-R4) and a microphone (B&K 4939) were arranged coaxially, facing in opposite directions. Canvas fabric was held taut on a rectangular frame and the frame was hung vertically between the loudspeaker and the microphone. The surface of the canvas fabric was perpendicular to the speaker-microphone axis. The distance between the speaker and the canvas fabric was 1,000 mm to obtain an acoustic far field. The microphone was moved on a linear stage to change the distance between the canvas fabric and the microphone from 10 to 300 mm. Measurement was performed 8 times at each position. To improve the signal-to-noise ratio (SNR), M-sequence-modulated signals were used as transmitted signals. An M-sequence is a pseudo-random signal composed of 0 and 1. An M-sequence-modulated signal is a burst signal phase modulated by the M-sequence. The SNR of received signals is increased by pulse compression using discrete cross-correlation. In this experiment, 1 cycles of a sinusoidal wave is assigned to 1 digit of the 8th-order M-sequence; the digit length is 255. After pulse compression processing, the processing result becomes equivalent to that where a 1-cycle signal at a high SN ratio is used. Because the processed result is equivalent to a short-pulse result, unwanted signals such as reverberation signals can be removed using a time gate. The processing gain of the 8th-order M-sequence is 24 dB. Eight cycles of an M-sequence-modulated signal was transmitted from the speaker. The carrier frequency of the signal was changed from 20 to 60 kHz. Figure 2 shows the result of Fourier transform of a pulse-compressed signal received at the microphone. From the frequency characteristics of the speaker shown in Fig. 2, the frequency range from about 20 to 50 kHz was used for measurements of transmission attenuation. A signal after the pulse compression is referred to as a received signal in this paper. The canvas fabric used in this experiment is a plain weave fabric made of cotton. Canvas fabrics are classified by a graded number system; therefore, we can control thickness. In this experiment, Nos. 11, 10, 9, and 6 were used. The numbers are opposite to the weight; so, a No. 11 canvas fabric is lighter than a No. 6 canvas fabric. The thickness and volume density of the canvas fabric used in the experiment are shown in Table 1.

3. Results and discussion

Transmission attenuation by canvas fabric was measured by observing the wave passing through the canvas fabric. Figure 3(a) shows the received signal without the canvas fabric and Fig. 3(b) shows the received signals passing through No. 10 canvas fabric at a carrier frequency of 30 kHz, where the distance between the speaker and the microphone was 1,100 mm. The wave was attenuated by passing through the canvas fabric. Figure 4 shows the result of Fourier transform of the received signals shown in Fig. 3. By changing the distance from the speaker, we obtained the frequency response at each distance, as shown in Fig. 4. From these measurements, we can obtain an acoustic field distri-

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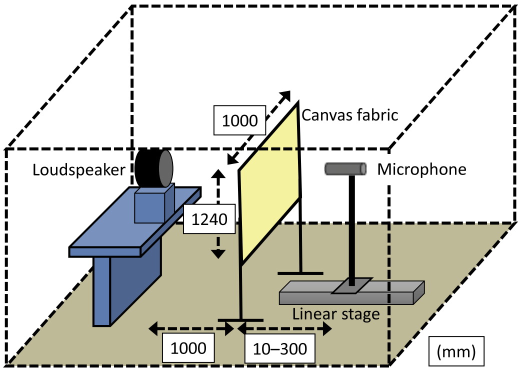

Fig. 1 Schematic configuration of experiment.

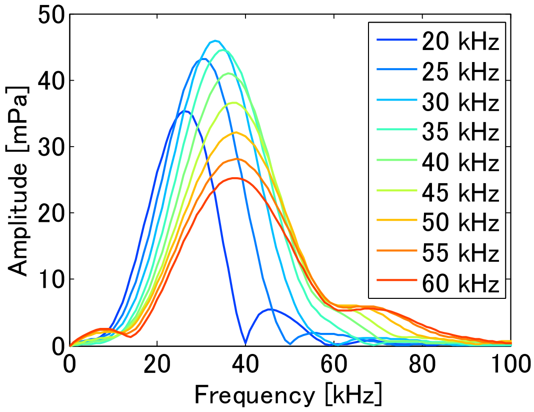

Fig. 2 Frequency characteristics of the speaker at carrier frequencies from 20 to 60 kHz.

Table 1 Classification of canvas fabric.

	Thickness [mm]	Volume density [kg/m^2]
No. 11	0.73	427
No. 10	0.83	474
No. 9	0.86	566
No. 6	1.22	485

bution at a desired frequency as a function of distance from the speaker. Figure 5 shows the relationship between the distance from the speaker and the amplitude of the received signal at a frequency of 30 kHz. Figure 5 also shows plots of theoretical lines assuming spherical (blue line) and cylindrical (green line) spreading. As shown in Fig. 5(a), a far field of the spherical wave was formed at the microphone position. From Fig. 5(b), it is found that the decrease in amplitude caused by the change in the distance from the speaker can be approximated as spherical spreading, that is, a spherically spreading wavefront is maintained after the passage through the canvas fabric. Then, transmission attenuation by the canvas fabric was estimated by calculating the difference between the approximation line of measurement with the canvas fabric and that without the canvas fabric, as shown in Fig. 6, within the frequency band of the speaker. Figure 7

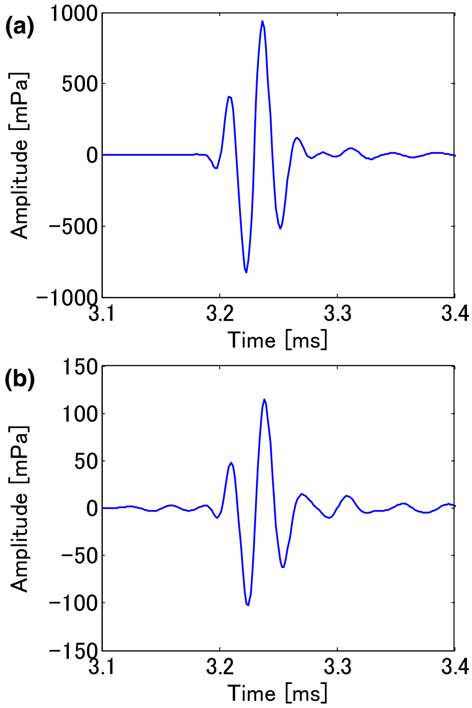

Fig. 3 Received signals at carrier frequency of 30 kHz and distance of 1,100 mm between the speaker and the microphone: (a) without canvas fabric, (b) with No. 10 canvas fabric.

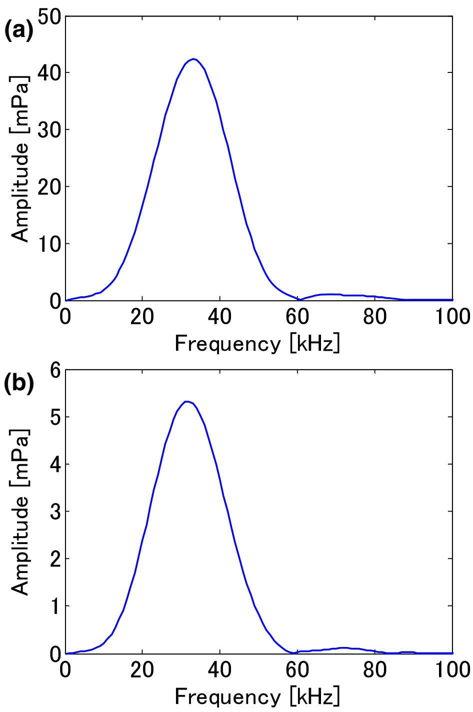

Fig. 4 Result of Fourier transform of received signals at carrier frequency of 30 kHz and distance of 1,100 mm between the speaker and the microphone: (a) without canvas fabric, (b) with No. 10 canvas fabric.

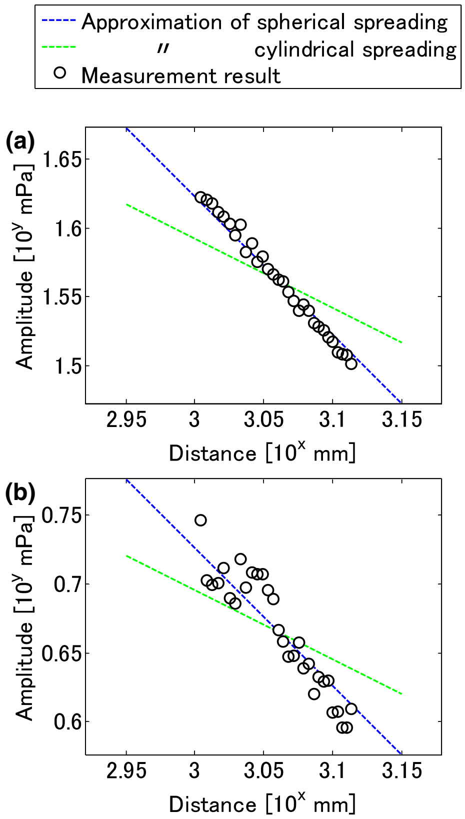

Fig. 5 Relationship between the distance from the speaker and the amplitude of received signal at a frequency of 30 kHz: (a) without canvas fabric, (b) with No. 10 canvas fabric.

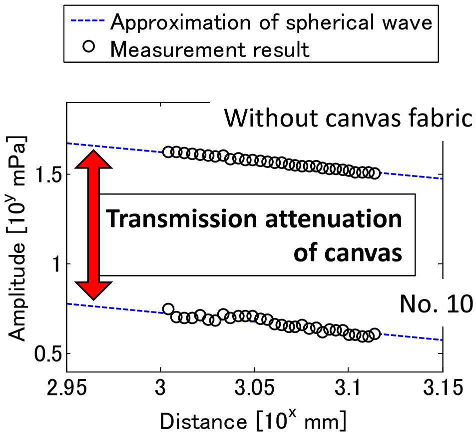

Fig. 6 Calculated transmission attenuation of canvas fabric at a frequency of 30 kHz.

shows the relationship between frequency and transmission attenuation by the canvas fabric. A linear regression line for attenuation by each canvas fabric is also plotted in Fig. 7. The regression expressions of transmission attenuation are shown in Table 2. It is found that transmission attenuation by No. 11, which has a thickness close to that of a T-shirt, is over 15 dB. In addition, the attenuation by all canvas fabrics tends to increase with frequency. Figure 8 shows the relationship

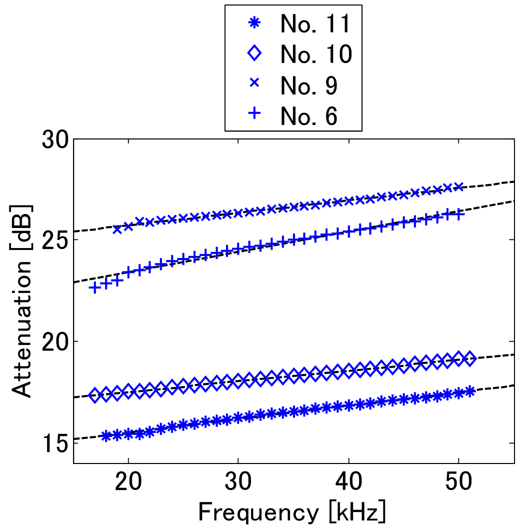

Fig. 7 Relationship between frequency and transmission attenuation by canvas fabric.

Table 2 Approximation of transmission attenuation by canvas fabric.

Canvas fabric	Approximation α: attenuation [dB], f: frequency [Hz]
No. 11	$\alpha = 14.2 + 6.6 \times 10^{-5} \cdot f$
No. 10	$\alpha = 16.4 + 5.3 \times 10^{-5} \cdot f$
No. 9	$\alpha = 24.5 + 6.1 \times 10^{-5} \cdot f$
No. 6	$\alpha = 21.4 + 1.0 \times 10^{-4} \cdot f$

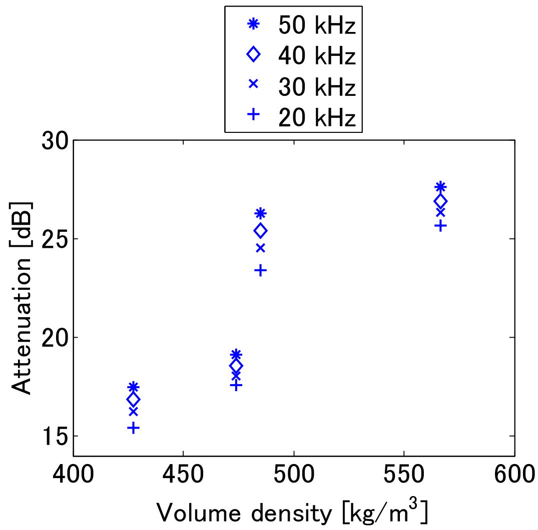

Fig. 8 Relationship between volume density of canvas fabric and transmission attenuation by canvas fabric.

between the volume density of the canvas fabric and transmission attenuation. The attenuation by the canvas fabric tends to be enhanced with the volume density of the canvas fabric. Because the transmission attenuation by the canvas fabric depends on the weave texture, the relationships between attenuation and density are complex. However, we found that the acoustic transmission attenuation by canvas fabric is greater than 15 dB in the 20–50 kHz frequency range. In addition, we obtained the relationship between frequency and transmission attenuation for typical fabrics. Using these acoustic transmission properties of fabrics, signal amplitude estimation for vital information of humans wearing clothes is possible.

4. Conclusion

To design an acoustic sensing system for movements underneath clothes worn, such as breathing and heartbeat, it is important to obtain transmission characteristics of clothes. In this paper, we presented ultrasonic transmission attenuation by canvas fabric as an example of a clothing material. To realize a high SNR and reverberation-free measurement, M-sequence-modulated signals were used. The acoustic transmission attenuation by even canvas fabric as thin as a T-shirt is greater than 15 dB in the 20–50 kHz frequency range. The relationship between transmission attenuation (dB) by a canvas fabric and frequency was shown by a regression line.

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