Measurement of road surfaces by reflection characteristics of airborne ultrasound

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1. Introduction

Ultrasonic transducers [1] are widely used to acquire target information such as position and motion [2–5] and medium information such as the speed of sound and attenuation [6–9], and for nondestructive testing [10–13]. In particular, the distance to a target is typically measured using an echo reflected from the target, i.e., the pulse-echo method. The pulse-echo method is based on the transmission of an ultrasonic pulse and time-of-flight (TOF) determination of the echo.

In an actual environment, echoes from objects other than the target, such as a wall or road, cause an artifact or degrade the accuracy of measurement. In this study, therefore, the reflection of airborne ultrasound from various road surfaces has been studied to identify the road surface or remove unwanted echoes. In this report, echoes from road surfaces with an asphalt pavement and block pavement are evaluated.

2. Method

2.1. Experimental setup

The experimental setup for measurement of echoes from road surfaces is illustrated in Fig. 1. The centers of the loudspeaker (Pioneer, PT-R100) and the microphone with its preamplifier (B&K, Type 4939 and 2670) were placed 500 mm above the road surface. Then, the loudspeaker and microphone were oriented with an angle of depression of 25° so that they were directed at a point on the road surface at a horizontal distance of approximately 1,000 mm from them. The measured road surfaces with an asphalt pavement and block pavement are illustrated in Fig. 2. In the asphalt-pavement road surface, there are random asperities. The long side and short side of the blocks in the block pavement are 190 and 90 mm, respectively, as illustrated in Fig. 3. The width and depth of the surrounding grooves are 10 and 4 mm, respectively.

To improve the signal-to-noise ratio (SNR) of the echo, pulse compression using a maximum-length sequence (M-sequence) was employed [4,6,9,14,15]. An M-sequence is a pseudo-random binary code generated from a linear feedback shift register (LFSR). A signal modulated by the M-sequence code is transmitted in pulse compression. Then, the received signal is correlated with the reference signal corresponding to

the transmitted signal. When codes of the echo in the received signal and the reference signal match, the high correlation value is obtained. Therefore, the TOF of the echo can be determined from the peak in the cross-correlation function.

In the experiment, the amplitude of the transmitted ultrasound was modulated by the M-sequence code. One sine wave was assigned to one binary word in the M-sequence code. The frequency of the transmitted ultrasound was 50 kHz. When one sine wave of 50 kHz, whose bandwidth is the same as that of the M-sequence-modulated signal, is transmitted, the directionality of the loudspeaker is broad in the perpendicular direction and narrow in the horizontal direction, as illustrated in Fig. 4. The M-sequence was a 10th-order sequence. Therefore, the SNR was improved by approximately 30 dB. An M-sequence-modulated signal of 1.5 V_{pp} was applied to the loudspeaker. The peak-to-peak sound pressure of the transmitted ultrasound, which was measured at a distance of 30 mm from the vibration plane, was approximately 2.3 Pa. Signals received by the microphone were recorded with a sampling frequency of 2 MHz. Then, they were correlated with the reference signal, which was a discrete M-sequence code, in the computer using MATLAB.

2.2. Measurement procedure

The received signal including echoes from the asphalt-pavement road surface is illustrated in Fig. 5(a). There are echoes of three cycles of the M-sequence modulated signal. The obtained cross-correlation function is illustrated in Fig. 5(b). There is truncation noise near the peaks caused by the 1st and 3rd cycles. Therefore, the peak caused by the 2nd cycle is used for measurement [15]. The wave around 20 ms is the echo that directly propagated from the loudspeaker. The wave around 23 ms is the echo reflected from the road surface directly under the loudspeaker and microphone. The subsequent waves are echoes from asperities of the road surface.

The amplitudes of echoes from the asphalt-pavement and block-pavement road surfaces are illustrated in Fig. 6. The horizontal axis indicates the distance from the point under the loudspeaker and microphone. The vertical axis, indicates the amplitude which is obtained by Hilbert transformation after compensation of attenuation of propagation by diffusion and the perpendicular directionality of the loudspeaker. In both cases, the echo amplitude decreases with increasing distance. These trends show the angular reflection characteristics of the road surfaces. In the case of the block pavement, high-

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(a) Arrangement of loudspeaker and microphone

(b) Front view of loudspeaker and microphone

Fig. 1 Experimental setup for measurement of echoes reflected from road surfaces.

(a) Asphalt pavement

(b) Block pavement

Fig. 2 Measured road surfaces of asphalt pavement and block pavement.

(a) Top view

(b) Side view

Fig. 3 Shape and size of single block.

(a) Perpendicular direction

(b) Horizontal direction

Fig. 4 Directionality of the loudspeaker, which was measured at a distance of 300 mm from the vibration plane.

(a) Received signal

(b) Cross-correlation function

Fig. 5 (a) Received signal including echoes reflected from the asphalt-pavement road surface and (b) obtained cross-correlation function.

amplitude echoes are found in places. Because their intervals correspond to the arrangement of the blocks, these echoes appear to be reflected from the grooves in the block pavement.

3. Results

To evaluate the echoes reflected from the asphalt-pavement and block-pavement road surfaces, B-mode images were formed by manual scanning of the loudspeaker and microphone. The scan length and pitch were 600 and 20 mm, respectively. The formed B-mode images and measured road surfaces are illustrated in Fig. 7. The point under each position of the loudspeaker is also plotted. The brightness indicates the amplitude on a logarithmic scale. In the case of the asphalt pavement, there is a random texture in the B-mode

Fig. 6 Amplitudes of echoes reflected from (a) asphalt-pavement and (b) block-pavement road surfaces.

image. In the case of the block pavement, the arrangement of grooves, which are all orthogonal to the ultrasonic-beam direction, can be recognized. The transmitted ultrasound was reflected from the asperities or grooves on the road surface. Echoes from the grooves were larger than those from the asperities.

Then, the measurement direction was rotated by 15, 30, and 45° from that in previous experiment on the block pavement, as illustrated in Fig. 8. The formed B-mode images are illustrated in Fig. 9. In the case of 15° rotation, only near by grooves can be recognized. In the cases of 30 and 45° rotation, however, grooves cannot be recognized; i.e., a random texture similar to that of the asphalt pavement was obtained. When the grooves are not orthogonal to the ultrasonic-beam direction, the reflected beam does not face the microphone. Therefore, high-amplitude echoes from grooves cannot be received.

4. Conclusions

In this study, echoes reflected from road surfaces with an asphalt pavement and block pavement were evaluated from B-mode images. In the case of the asphalt pavement, echoes from random asperities on the road surface were found. In the case of the block pavement, high-amplitude echoes from grooves orthogonal to the ultrasonic-beam direction were found in addition to random echoes. However, echoes from grooves at angles of more than 15° were not found. To recognize the overall arrangement of asperities on road surfaces, measurement from various angles is required.

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Fig. 7 Amplitudes of echoes reflected from (a) asphalt-pavement and (b) block-pavement road surfaces.

Fig. 8 Measured area on block-pavement road surface.

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Fig. 9 B-mode images of block-pavement road surfaces.

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