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Estimation of road roughness using amplitude statics of ultrasound reflected from road surface
路面からの反射波の振幅統計量を用いた路面凹凸の推定

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1. Introduction

We have been investigating the difference of reflection characteristics of ultrasound caused by the road roughness[1, 2]. In this report, we describe the method of evaluating the road roughness using the amplitude statistics of ultrasound reflected from road surface by the experiments on the actual asphalt road surfaces and the simulation by the 2D FDTD method.

2. Experiment and simulation

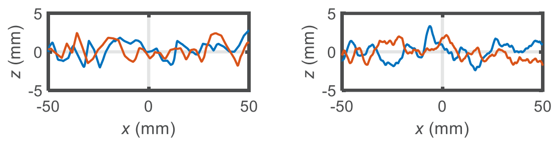
2.1. Road surface shape

Figure 1 shows three types of asphalt road surfaces having different roughness for the experiments, and **Fig. 2(a)** shows the height z measured by the 3D scanner. It was normalized so that the average level of each road surfaces is 0 mm. The standard deviation of z, σ_z was used as the evaluation index of road roughness. In order from asphalt 1, σ_z is 1.3, 1.0, 0.52 mm. The spatial frequency spectrum of road height along the x direction is shown in **Fig. 3** in order to investigate the characteristics of the roughness in the horizontal direction. From Fig. 3, we see that the horizontal spatial frequencies of the three road surfaces are nearly same.

In the FDTD simulation, road surfaces having different shapes were generated by changing the phase of the average spatial frequency spectrum of Fig. 3 randomly. Then, the roughness in the z (vertical) direction of the road surface was changed using σ_z as an index. The examples of road surfaces generated on a computer are shown in **Fig. 2(b)**.

2.2. Measurement environment

An experimental setup for transmitting and receiving ultrasounds is shown in **Fig. 4**. Using a loudspeaker and a microphone attached at height of 250 mm from the road surface, the ultrasound was radiated from the vertical direction to the road surface, and the reflected wave was received. Burst waves with a time width of 1 ms ware transmitted



(a) measured with the 3D scanner (b) generated on a computer

Fig.2 Cross-section shape of road surfaces (σ_z = 1.0 mm)

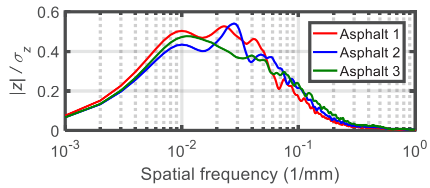
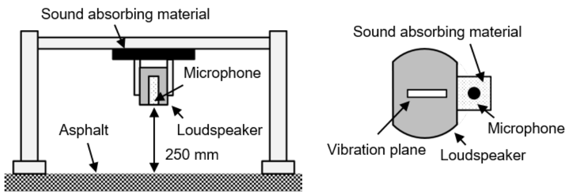


Fig.3 Spatial frequency spectrums in x directions on the road surface



(a) Side view (b) Front view

Fig.4 Experimental setup


(a) Asphalt 1 (σ_z = 1.3 mm) (b) Asphalt 2 (σ_z = 1.0 mm) (c) Asphalt 3 (σ_z = 0.52 mm)

Fig.1 Measured road surfaces

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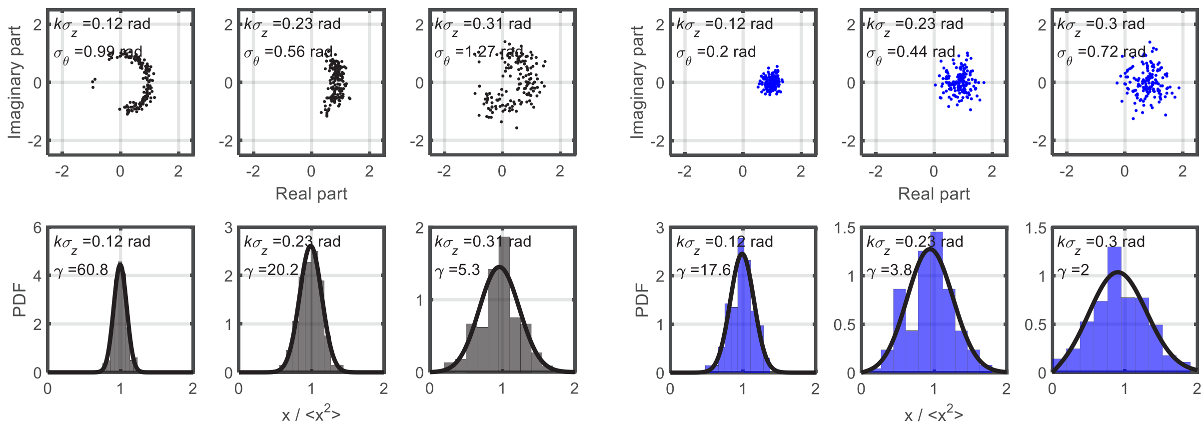

(a) Experiment results (b) Simulation results

Fig.5 150 signals on complex plane and PDF, fitting result to the Rice distribution (12.5 kHz)

with varying frequencies. The experimental equipment was moved by 50 mm step and measured at 150 points.

In the simulation, the sound pressure and the particle velocity were calculated for an analysis space of 1000 mm in width, -10 mm in the ground to 350 mm in height. I set the boundary of the sound pressure to zero on the road surface and the PML absorption boundary on the other boundary. The other conditions were the same as those in the experiment, and the simulation was carried out by changing the shape of the road surface 150 times.

3. Acquisition of amplitude statistic value

Reflected waves from the rough surface randomly change due to interference of reflected waves from some reflection points[2].

Amplitude and phase are estimated by averaging with a width of 0.25 ms at center of burst signal where sufficient interference occurs. Amplitude probability density distribution (PDF) using 150 reflected waves with different road surface shapes was evaluated by Rice distribution.

The Rice distribution is one method of evaluating the reflected wave from the roughened surface[1] and is expressed by the following expression.

$$p(x) = 2x(1+\gamma) \times \exp(-((1+\gamma)x^2+\gamma))I_0(2x\sqrt{\gamma(1+\gamma)})$$

Here, p is the probability density, x is the amplitude, and I_0 is the Bessel function of the first kind of zero-order. γ is the energy ratio between the coherent component and the incoherent component of the signal and obtained by $\gamma = s^2/\langle n^2 \rangle$ from the signal effective value s and the root mean square of noise $\langle n^2 \rangle$. When $\gamma = 0$, PDF is a Rayleigh distribution, and when γ is large, it is a normal

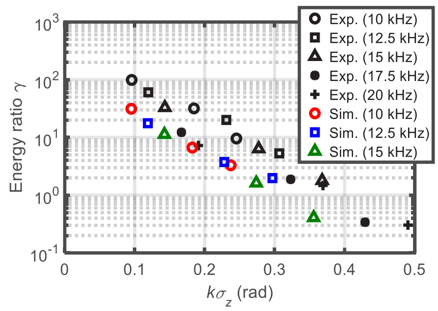

Fig.6 Relationship between $k\sigma_z$ and γ

distribution. **Figure 5** shows the fluctuation on the complex plane when the frequency is 12.5 kHz with $k\sigma_z$ and σ_θ (standard deviation of phase), γ. From Fig. 5, σ_θ and γ are larger in the experiment than the simulated results. This large σ_θ is caused by the distance fluctuation between the loudspeaker and the road surface in the experiment. **Figure 6** shows results of experiments and simulations. γ decreases exponentially with increasing in $k\sigma_z$. Although both trends are consistent, γ of simulation results is smaller than experimental results. However, it is suggested that using of Rice distribution evaluation of road roughness is possible.

4. Conclusion

In this report, we investigated the relationship between the amplitude statistics of ultrasounds reflected from the road surface and the road roughness by the experiments and the simulations. It is clear that the estimation using Rice distribution is valid. More quantitative and theoretical discussion is sought in future.

References

1. H. Hachiya: MASJ, 26, pp.166-172, 1999.
2. N. Shinoda: ASJ (Spring), pp.999-1000, 2018.