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Analysis of reflected ultrasound from road surface and surrounding obstacles

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1. Introduction

The airborne ultrasonic waves are widely used to obtain object information such as position and motion. In this paper, we investigate whether it is possible to detect the position and shape of obstacles even on rough surfaces such as asphalt using the two-dimensional FDTD method.

2. Generation method of rough road surface

The rough road surfaces used in the simulation were generated using the horizontal mean spatial frequency spectrum of the real road surface height z measured with a 3D scanner. By randomly giving an initial phase to each of these spectra, a road surface with a different shape is obtained. The amplitude probability density function of the real road surface roughness is not a normal distribution but has an asymmetric shape. The cumulative density function was used to transform the normally distributed surface generated from the spectrum to match the distribution of the actual road surface. The roughness of the road surface in the z (vertical) direction was set by arbitrarily giving the product $k\sigma_z$ of the standard deviation σ_z[m] of the road surface height and the wavenumber k[rad/m]. An example of the generated road surface is shown in Fig. 1($k\sigma_z = 0.45$). The rough road surface was generated by controlling both the probability density distribution of the road surface roughness and the spatial frequency characteristics.

3. Evaluation of reflected signal from rough surfaces

The reflected wave from a road surface varies randomly due to the interference of reflected waves from multiple reflection points. 90 different road surfaces ($k\sigma_z = 0.46$) are prepared, and the reflected wave is shown in the upper panel of Fig.2. After the demodulation of these RF signals, amplitude information was obtained, shown in the lower panel of Fig.2. Then, the amplitudes in the range from 0.1 ms to 0.3 ms after the arrival of the reflected wave are averaged and normalized. The amplitude and phase information of reflected signals on the complex plane in this range is shown in Fig.3. The amplitude distribution of these signals in the complex plane can be evaluated by the Rice distribution.

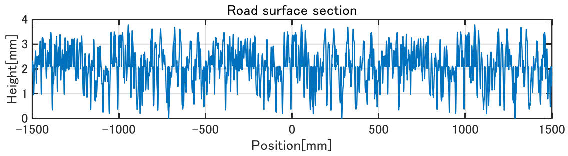

Fig 1. Example of road surface ($k\sigma_z = 0.45$)

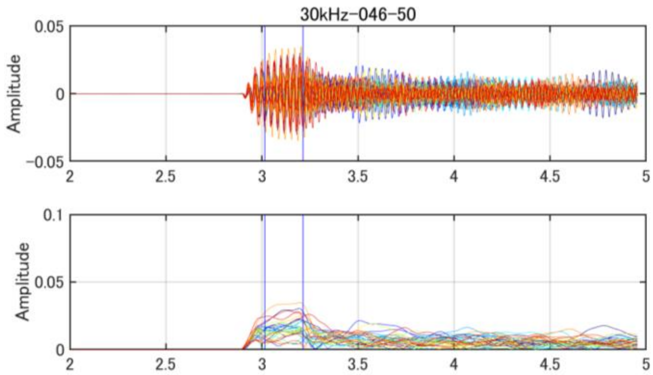

Fig 2. Received signal (top), amplitude (bottom)

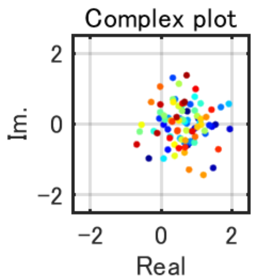

Fig 3. Complex plane plot

Rice distribution is one of the methods to evaluate reflected signals from rough surfaces and is expressed by the following equation.

$$p(x) = 2x(1+\gamma) \times \exp\left(-\left((1+\gamma)x^2+\gamma\right)\right) \mathrm{I}_0\left(2x\sqrt{\gamma(1+\gamma)}\right)$$

p: probability density, x: amplitude, I_0: zero-order deformed Bessel function.

4. FDTD Simulation

Using the generated rough road surface ($k\sigma_z$= 0.45), simulations were performed by the FDTD method. In the simulation, the transmitter/receiver and object arrangements were set up as shown in Fig.4. A four-wave sine burst signal was used as the transmitting signal, with a center frequency of 30 kHz. The transmitter, a speaker, was placed at a height of 0.5 m, and the receiver, two microphones, were placed vertically directly above the speaker at heights of 0.568 m and 0.576 m. The height of the obstacle was set to 0.2 m. The calculation area for the simulation was 1.5 m in front of and behind the speaker, 0.5 m between the speaker and the floor, and 0.7 m between the speaker and the ceiling, with a grid size of 0.25×10^{-3} m. The walls and ceiling were the absorbing boundaries.

5. Simulation results

Figure 5(a) shows the reflection signal when the road surface is flat. The horizontal axis represents time [ms] and the vertical axis represents amplitude. The position and color of the dashed lines in Fig.5(a) are the arrival time of the signal corresponding to the path of the colored arrow in the reflection path diagram in Fig.6, respectively. The red arrow indicates the path of the reflection from the bottom edge of the obstacle. The blue and green arrows indicate the paths of the edge waves from the upper left and upper right corners of the obstacle.

Figure 5(b) shows the reflected signal in the case of an irregular road surface. In this case, the reflected wave from the bottom edge (red arrow) can be observed, but the two reflected waves from the top edge (blue and green arrows) cannot be observed.

Next, the position of the lower edge was estimated using the reflected wave from the rough surface (Fig.7). The phase difference φ between the two received waves was used to estimate the grazing angle θ between the horizontal line and the microphone- lower edge line segment. The following equation was used.

$$\sin\theta = \frac{\lambda\phi}{2\pi m_w}$$

m_w: Distance between microphones

Figure 8 shows the results of estimation on each of 90 different road surfaces ($k\sigma_z$=0.45). It was found that the location of obstacles could be estimated almost accurately even on rough surfaces such as asphalt.

6. Conclusion

The accuracy of estimating the location of obstacles on various asphalt road surfaces was examined using FDTD simulations. The results show that the distance can be estimated almost accurately. In the future, we plan to investigate a method to estimate the height of obstacles even on rough road surfaces.

References

Y. Tan *et. al.*, Proc. Symp. Ultrason. 24 Electr. **42**, 2Pa-2-3, 2021.

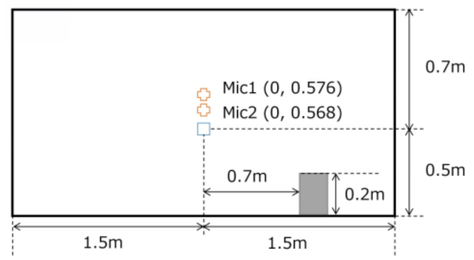

Fig 4. Configuration of FDTD simulation

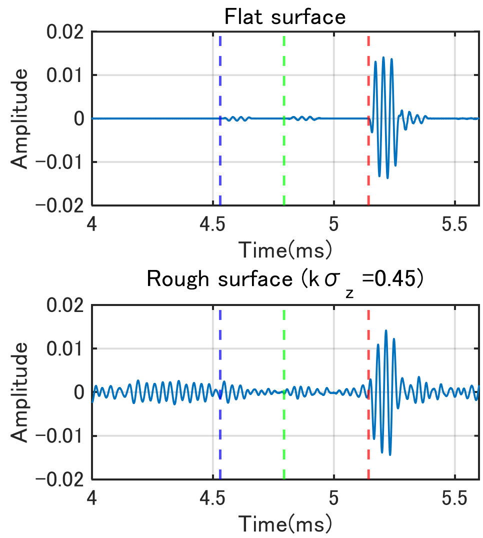

Fig 5. (a) Flat surface (b) Rough surface

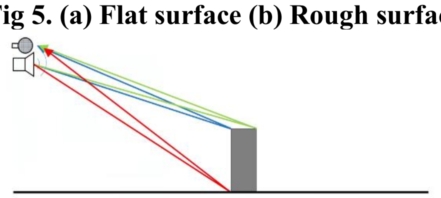

Fig 6. Reflect signal paths

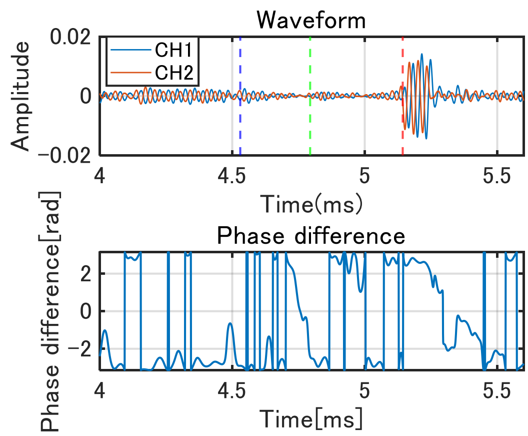

Fig 7. Waveform and phase difference

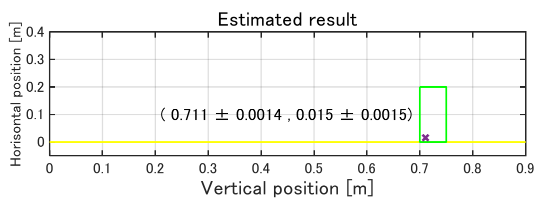

Fig 8. Estimated results