

Theoretical Evaluation of μ Measurement with Icy Road using Backscattered Light

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In recent years, autonomous driving technology has continued to develop increasingly, and Level 4 (driver-free) services have been put into practical use in some parts of Japan and overseas. However, their operation remains on dry roads. A quantitative measurement of friction coefficient (μ) with icy road is necessary especially in snowy country.

Also, In the measurement of the friction coefficient (μ) of icy road surfaces using NIR backscattered images, multilayer reflections composed of reflections from both the ice surface and the underlying road surface layer like Fig.1 are measured. In the figure, layers 1, 2, and 3 represent air, ice, and asphalt, respectively. In particular, the reflected light from layer 2 is considered to depend on both the measurement wavelength and the surface roughness. Authors demonstrated that the backscattered light intensity ratio $I_{r,1500}/I_{r,1300}$ from an icy road surface is sensitive to the road surface friction coefficient (μ). Here, $I_{r,1500}$ and $I_{r,1300}$ represent the background scattered light intensities at wavelengths of 1500 nm and 1300 nm, respectively. In this study, these reflection characteristics were investigated, and the validity of measuring the friction coefficient (μ) of icy road surfaces using backscattered light was theoretically verified.

Eq. (1) shows that the backscattered light intensity I_r is expressed as the sum of S_{12} and T_{21} :

$$I_r = S_{12} + T_{21} \quad (1)$$

Where S_{12} is the intensity of the backscattered light from the boundary between layer 1 and layer 2, and T_{21} is the intensity of the backscattered light from the boundary between layer 2 and layer 3. Therefore, I_r ratio between 1300 nm and 1500 nm can be expressed as follows:

$$\frac{I_{r,1500}}{I_{r,1300}} = \frac{[S_{12} + T_{21}]_{1500}}{[S_{12} + T_{21}]_{1300}} \quad (2)$$

Since ice strongly absorbs light at 1500 nm, $T_{21,1500}$ becomes extremely small. On the other hand, S_{12} exhibits no wavelength dependence. Therefore, it can be seen that only $T_{21,1300}$ is sensitive to μ . Consequently, it was determined that the reason the $I_{r,1500}/I_{r,1300}$ is sensitive to μ is attributable to $T_{21,1300}$.

Regardless of the measurement wavelength, surface-scattered light S_{12} is sensitive to μ . On the other hand, T_{21} is extremely small at 1500 nm. So, we clarified the relationship between the normalized reflected light intensity $I_{\#}/I_{\#2000}$ at 1500 nm for icy road surface and its surface roughness.

Fig.2 shows the results of comparing $I_{\#}/I_{\#2000}$ at 1500 nm and I_{1500}/I_{1300} across various surface roughness. Here, $\#$ is the grid number of the sanding paper used to polish the surface of test pieces as icy road. The figure clearly shows that both $I_{\#}/I_{\#2000}$ and I_{1500}/I_{1300} are sensitive to $\#$, but the former's sensitivity is particularly high.

From these results, it is shown that using the absolute value of image intensity at 1500 nm can achieve higher accuracy than I_{1500}/I_{1300} for icy road friction coefficient (μ) measurement using an NIR camera.

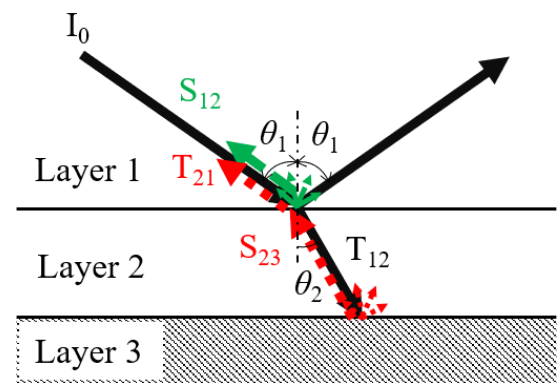


Fig.1 Schematic of background light scattering in three layers

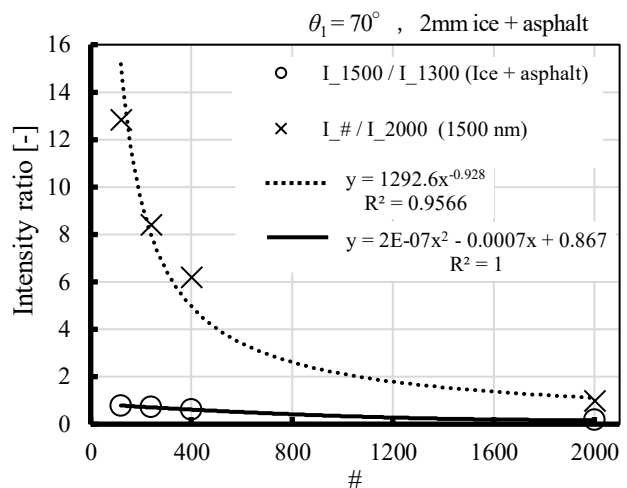


Fig.2 Comparison of intensity ratio between I_{1500} / I_{1300} and $I_{\#} / I_{\#2000}$ with icy asphalt