Application of Physical Optics on Caustics Region of Curved Surfaces for Ray Tracing Simulation of Tunnel Propagation

Y. Kishiki$^1,2$, J. Takada$^2$, G. S. Ching$^1$, N. Lertsirisopon$^1$, M. Kawamura$^1$, H. Takao$^3$, Y. Sugihara$^3$, S. Matsunaga$^3$ and F. Uesaka$^3$

$^1$Kozo Keikaku Engineering Inc., $^2$Tokyo Institute of Technology, $^3$JGC CORPORATION
Kozo Keikaku Engineering Inc., Nakano-ku, Tokyo 164-0012, Japan
E-mail: y-sanoh@kke.co.jp

Introduction

The curved surfaces and edges are difficult to handle in ray tracing simulations. In this work, a new ray tracing method which models the reflection on the curved surface was implemented and physical optics is applied on the caustics region. Path gain simulation results for a square and horseshoe model are then compared with measurements made inside an arched tunnel. Next, the effect of rough surface is introduced in the simulation, and results are again compared with measurement.

Treatment of the Curved Surface

To search the reflected point which satisfies Fermat’s principle on the curved surface, the imaging method is used. The curved surface is divided into several plates during ray tracing, resulting in many rays on these plates. Then the shortest path is chosen, and the reflected field is calculated considering the distortion of the wave front [1]. The reflection coefficient on the curved surface is written as

$$\tilde{R}^c = \tilde{R} \sqrt{\frac{s'}{s'} + s} \sqrt{\frac{\rho}{\rho + s} e^{-jk}}$$

where $\tilde{R}$ is the dyadic reflection coefficient, $\rho$ is the principle radii of curvature and $s'$, $s$ are the distance between incident point and reflection point, and reflection point and observed point, respectively. The reflection coefficient on the curved surface becomes more than unity near the caustics region. In this case, the scattering field from the curved surface is introduced using physical optics.

Roughness of the Surface

A rough surface can be modeled by a continuous stationary random process with normal distribution [2]. For the specular direction, the scattering coefficient of rough surface is

$$\tilde{R}_r = \tilde{R} \exp \left\{ -8 \left( \frac{\pi \Delta h \cos \theta_i}{\lambda} \right)^2 \right\}$$

where $\Delta h$ is the standard deviation of the normal distribution of the local surface roughness, and $\theta_i$ is the incident angle to the surface.

Results and Conclusions

In the case that Tx and Rx are placed at the center of the tunnel width, the path gain for the square model is similar to the measurement data. The path gain on the horseshoe model produce higher values than the measurement data. This problem occurred near caustics, so physical optics is applied. On the other hand, when Tx and Rx are placed close to a side wall, the path gain on the horseshoe model and measurement data are similar. In the presentation, the results including physical optics will be shown. For rough surfaces, results with varying $\Delta h$ reveal that path gain decreases when $\Delta h$ is large. The effect of rough surface in the case of center position is larger than the side position, and results will be closer to the measurement data when $\Delta h$ is 30 mm.

References
