KAIST RDMIS Radiation Detection and Medical Image Sensor laboratory

Validation of Custom Monte Carlo simulation of Light Transport in Scintillator

Hyunwoong Choi [a], Kilyoung Ko [a], Junhyeok Kim [a], Wonku Kim [a], Sangho Lee [a], Youngsun Yi[b], Gyuseong Cho [a*]
[a]Department of Nuclear & Quantum Engineering, Korea Advanced Institute of Science and Technology (KAIST)
[b]Depart of Nuclear Engineering, Khalifa University
*Corresponding author : gscho1@kaist.ac.kr

1. Introduction

Scintillator crystals are widely used as radiation detector in wide range of field. The principle of scintillation detectors is counting scintillation light produced by ionizing radiation.

Since the light propagation in the crystal and collecting the light at photodetector affects many parameters. In this paper, we make our custom light transport Monte Carlo simulation inside of the scintillator and validate it with other results.

2. Basic Theory and Simulation Process

According to UNIFIED model, the surface is a collection of planar micro-facets. Polished surface is smooth surface that specular reflection occurs. Rough surface, in contrast, is a non-uniform surface that has many local micro-facet.

The probability of transmission and reflection for unpolarized light at the surface is determined by Fresnel's law (1) and Snell's law (2).

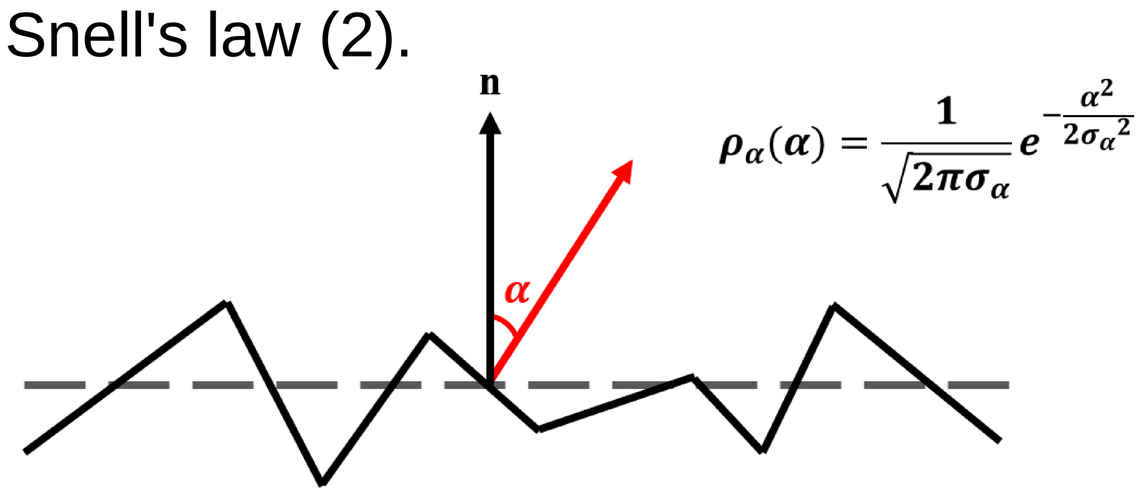

Fig. 1. UNIFIED surface model

$$R = \frac{1}{2}\left\{\left(\frac{n_1\cos\theta_i - n_2\cos\theta_t}{n_1\cos\theta_i + n_2\cos\theta_t}\right)^2 + \left(\frac{n_1\cos\theta_t - n_2\cos\theta_i}{n_1\cos\theta_t + n_2\cos\theta_i}\right)^2\right\} \quad \textbf{(1)}$$

$$\frac{\sin\theta_i}{\sin\theta_t} = \frac{n_1}{n_2} \quad \textbf{(2)}$$

Assume that the surface of crystal is polished, the initial angle of the light decides whether it is detected or not. The two types of reflectors are used widely, specular reflector (ESR, 3M) and lambertian reflector (Teflon tape).

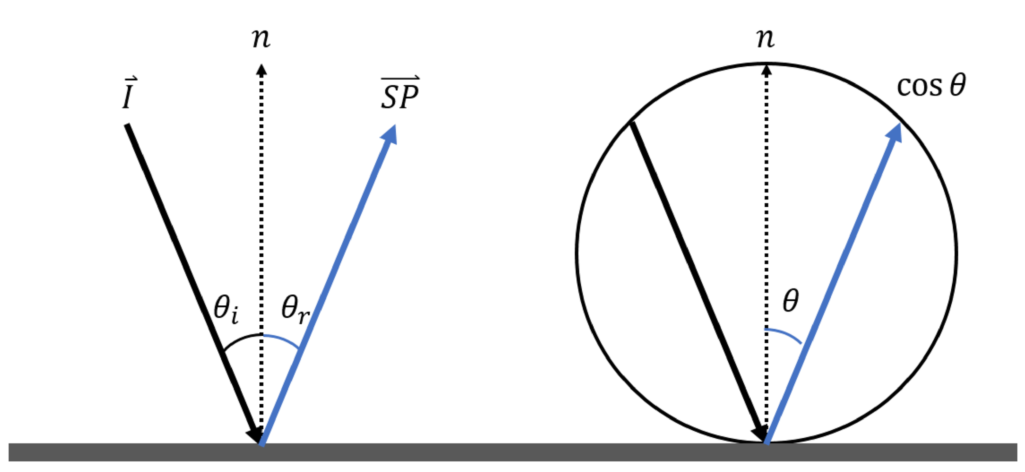

Fig. 2. Specular reflection and lambertian reflection

The temporal light emission distribution $p_{sc}(t)$ is expressed by linear combination of bi-exponential equation using rise time (τ_r) and decay time (τ_d). Bulk absorption length (λ_{att}) is composed of scattering length (λ_{sc}) and absorption length (λ_{abs})

$$p_{sc}(t) = \begin{cases} \frac{1}{\tau_d - \tau_r}\left[e^{\frac{-(t-\Theta)}{\tau_d}} - e^{\frac{-(t-\Theta)}{\tau_r}}\right] & if\ t \geq 0 \\ 0 & if\ t < 0 \end{cases} \quad \textbf{(3)}$$

$$\frac{1}{\lambda_{att}} = \frac{1}{\lambda_{sc}} + \frac{1}{\lambda_{abs}} \quad \textbf{(4)}$$

First step of Monte Carlo simulation is deciding crystal geometry, material, surface treatment, reflector type and γ-ray interact position. Next step is generating isotropic distributed light. Since polar and azimuth angle are determined from below equations, initial direction of light also determined by Eq. (5)

$$\theta = \cos^{-1}(1 - 2RN)\ [0 \leq RN \leq 1]$$
$$\varphi = 2\pi RN\ [0 \leq RN \leq 1] \quad \textbf{(3)}$$
$$\vec{v} = (\sin\theta\cos\varphi, \sin\theta\sin\varphi, \cos\theta) \quad \textbf{(4)}$$

When the light generated with random direction with the initial position, it will arrive the nearest face in its direction. After the light arrives at the detection surface, bulk absorption length and reflectivity of reflector are applied.

3. Simulation Result

A 3×3×20mm^3 LYSO is modelled and rise time and decay time is 90ps and 430ns respectively. Also we assume 138mm bulk absorption length at the peak wavelength of the emission spectrum of LYSO, 430nm.

The 3×3mm^2 photodetector is coupled to the crystal with optical grease (1.465 refractive index) and reflectors also coupled to crystal with air (1 refractive index). We validate our custom Monte Carlo simulation by comparing the result of Cates'. We can verify that our custom Monte Carlo simulation code is well designed.

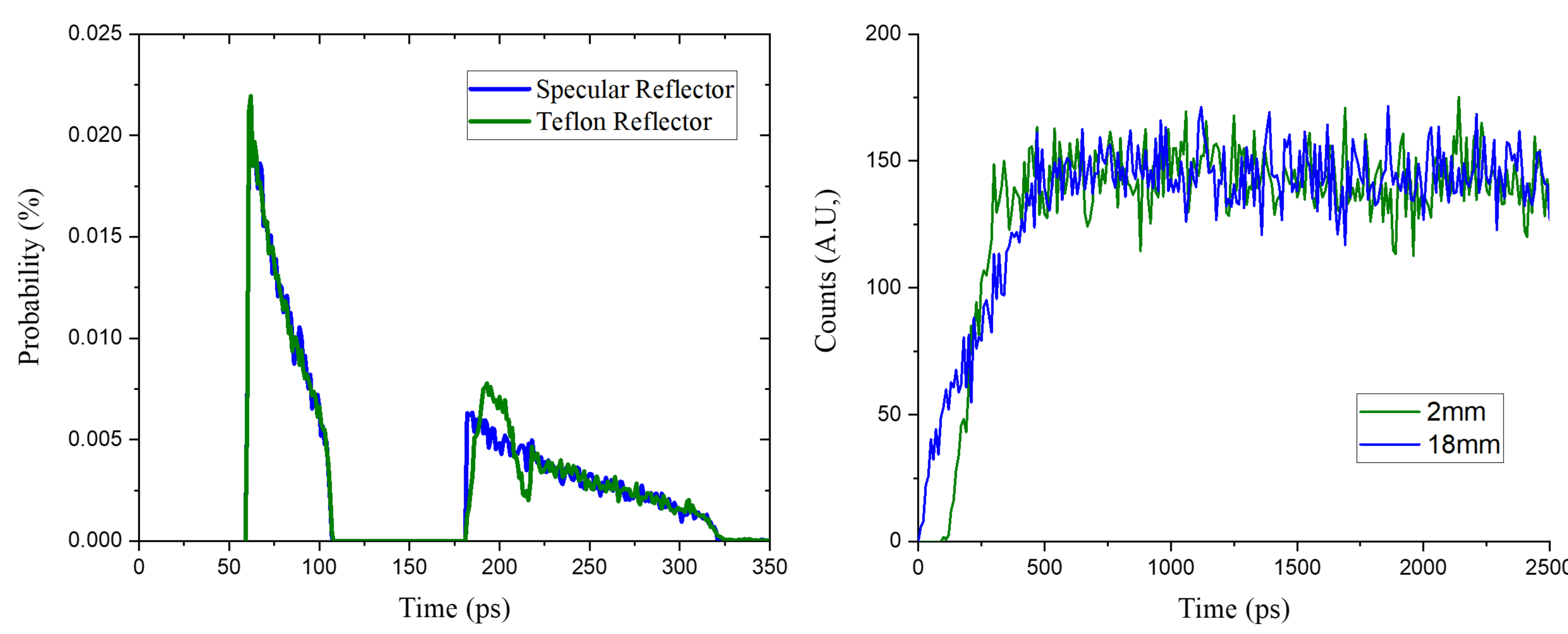

Fig. 3. Result of custom Monte Carlo simulation

4. Conclusion

In this paper, we show how to make custom light transport Monte Carlo simulation. And we validate out simulation is well matched with various references.

5. Acknowledgement

This research was supported by the KAI-NEET Institute (or the KAIST-KU Joint Research Center), KAIST, Korea and other funding organization.