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HOW TO CHOOSE SIMULATION PARAMETERS TO IMPROVE ACCURACY?

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Abstract

Optical design and light propagation modeling would be significantly harder and less precise without simulations. As the LEDs are becoming more and more popular, simulations are also required in order to satisfy their diverse professional applications.
In modern light sources, the manufacturer provides the luminous intensity distribution database files for the simulations, in international standard formats or with “Ray Files”, which define millions of guided ray vectors. This file contains all photometrical information about the light source. Thus, the software can calculate with these vectors quickly and easily.
However, many questions arise about simulations. For example, how may traced rays are required to achieve accurate results? What is the relationship between the traced rays and the simulation time? What is the effect of complex geometries on the simulation results? Can we improve accuracy with implementing a measured spectral power distribution?
The aim of this paper is to answer some of these questions using a professional light-modeling and simulation software at the BUTE–MOEI.

Keywords: photometrical simulation, optical simulation, ray file

1 Calculation methods of optical simulation software

Modern optical simulation algorithms can be separated into three sub-categories based on their used calculating methods (BRO, 2006):

- Sequential ray tracing: the algorithm substitutes the light source with directed rays and guides these rays through the pre-defined optical elements in a determined order. Ray tracing is capable of simulating a wide variety of optical effects, such as reflection and refraction, scattering, and dispersion phenomena (such as chromatic aberration).
- Non-sequential ray tracing: similar to the one above, but in this case the rays can reach one surface in multiple times and in any order. Ray scattering is allowed. The order of the ray tracing is arbitrary.
- Finite-difference time-domain: mainly used in the design of micro-optical systems where there are optical elements at a size of the wavelength of light.

The mathematical algorithms applied by the specific software are mainly confidential but generally based on the Monte Carlo method. Using this method, deterministic problems can be solved with the sequence of random events applying probability density functions for the unknown parameters. In contrast to deterministic methods, due to the random sampling, the Monte Carlo method needs less calculation (computation) and less boundary condition to the geometries. Thus, simulation time is significantly shorter and for the evaluations, statistical estimation methods are applied (Pokrádi, 2010).
As a ray reaches a surface, its further path depends on the pre-defined optical properties, what the following equation (BRDF - Bidirectional Reflectance Distribution Function) (Nicodemus, 1965) describes:

$$f_r(\omega_i, \omega_0) = \frac{dL_r(\omega_0)}{dE_i(\omega_i)} = \frac{dL_r(\omega_0)}{L_i(\omega_i)\cos\theta_i d\omega_i} \qquad (1)$$

where

ω_i	is the vector directed to the light source;
ω_0	is the vector directed to the observer (sensor);
L	is the luminance;
E	is the illuminance;
i	is incoming parameter;
r	is reflected parameter;
θ	is the angle between the surface normal and the ray.

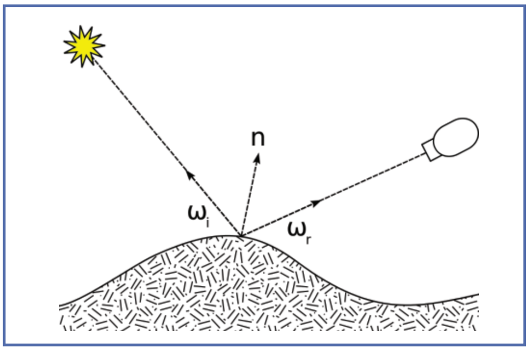

Figure 1 – Incoming, outgoing, and normal vectors used in defining the BRDF

In a photometric approach, BDRF defines the surface reflection in function of the illuminance and the observer's location. BDRF depend on the wavelength, as well as the structural and optical properties of the material (Nicodemus, 1965).

2 Correlation between traced ray number and simulation time

As expected, with the increase of the number of traced rays the simulation time also increases (Gémesi, 2011).

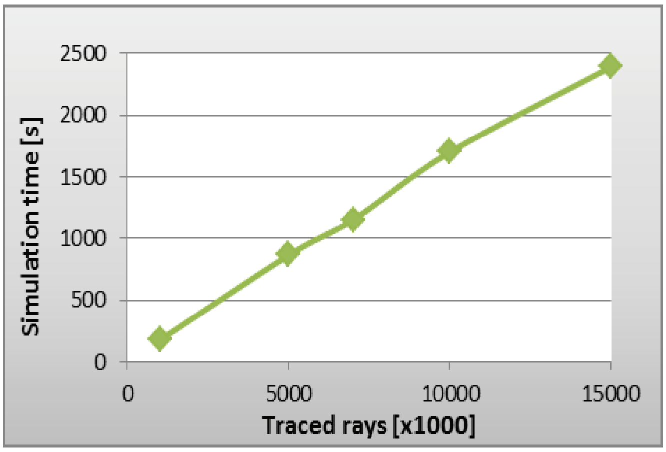

Figure 2 – Correlation between the traced ray number and simulation time

With the increase of the number of rays the simulation time grows linearly. However, in order to get properly accurate simulation results, the applied ray number should be sufficient.

3 Effect of traced ray number on the simulation accuracy

As the simulation time increases with the number of traced rays it is important to apply the sufficient number of rays for accuracy. We have simulated various photometric quantities without defined optical geometries to determine the stability of the results.

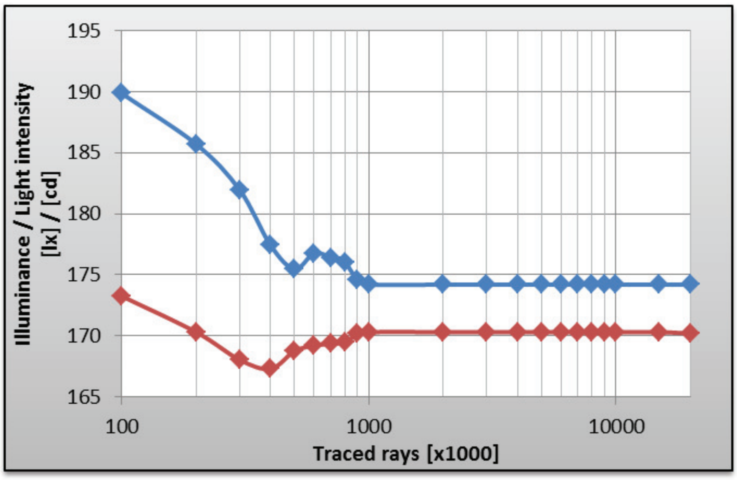

Figure 3 – Simulated illuminance and luminous intensity results, in function of the traced ray number (red-illuminance, blue-light intensity)

The results show that the number of the traced rays should be more than 1 million in the case when there isn't any defined geometry in the simulation, which could influence the path of the rays. Above 1 million rays we didn't find significant variation in the simulation results. The standard deviation was around zero (Gémesi, 2011).

4 E ffect of optical geometries on the simulations

Without optical geometries using 1 million rays the simulation can be sufficiently precise and time efficient. However we need to examine how many traced rays are required in order to get accurate results in case of complex geometries. Due to the more difficult calculations, the simulation time shall be longer. During the experiments, we applied 10 surfaces with defined optical parameters (reflection, transmission and absorption) between the light source and the illuminance sensor. The simulations have been conducted with 1, 5, 7, 10 and 15 million traced rays (Gémesi, 2011).

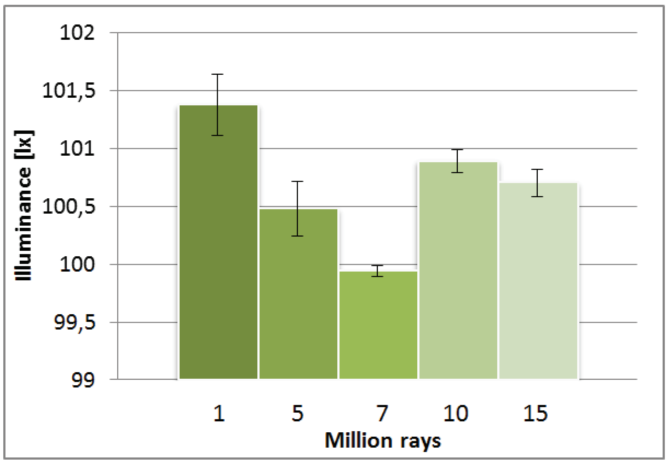

Figure 4 – Simulated illuminance results with 10 defined surfaces

The difference between the results is very small. The average value is slightly higher at 1 million rays, and the standard deviation is bigger at 1 and 5 million rays. Thus we can say that complex geometries require above 5 million traced rays.

5 Improving simulation accuracy with measured spectral power distribution

The Ray file doesn't contain any information about the spectral power distribution of the light source, thus the simulation can be supplemented with the measured spectral power distribution of the LED (Figure 5). We used a Konica Minolta CS-1000 spectroradiometer camera for the measurements.

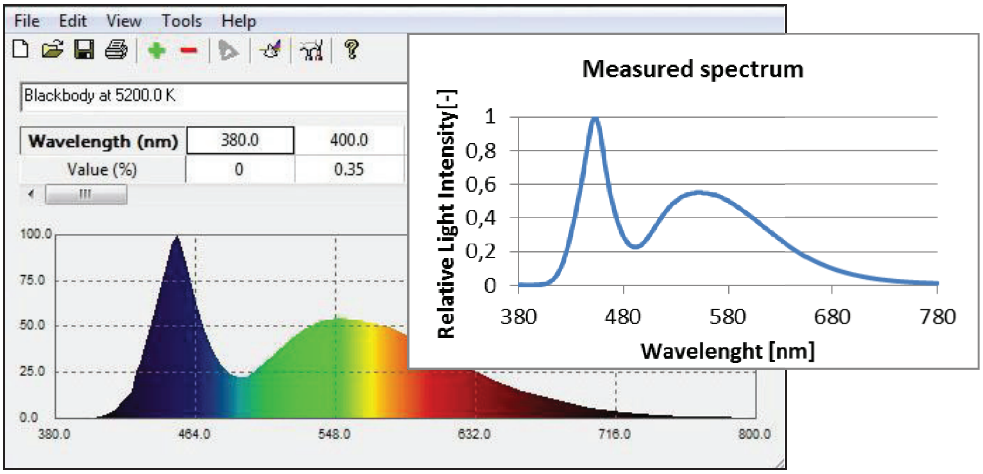

Figure 5 – Implementation of the measured spectral power distribution into simulations

The simulation results show that implementation of the spectral power distribution improved the results by 1-2 %. Therefore, its effect is significant.

6 Improving simulation accuracy with measured spectral power distribution

We made several simulations to examine correlations between the numbers of traced rays and other parameters (e.g. the duration of the simulation process, accuracy of the simulations and the effect of complex geometries). The sufficient number of traced rays can be determined depending on the applied geometries. Beside this we can also implement spectral measurement results to improve accuracy.

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