The spectral radiosity simulation program LUMOS for lighting research applications

Dipl.-Ing. Frederic Rudawski
Technische Universität Berlin, Fachgebiet Lichttechnik
Deutschland, Berlin, Einsteinufer 19

Summary

LUMOS is a spectral radiosity simulation tool developed for lighting research applications in MATLAB. It provides an easy-to-use frontend, consisting of a GUI and an editor, which enables the user to create artificial lighting and daylight spectral simulations for arbitrary wavelengths without the need of additional software or code programming knowledge. Spectral fisheye images can easily be derived for any position and viewing direction. In combination with the complementary Lighting Toolbox for MATLAB and Octave, this allows for an in-depth spatial and spectral evaluation of the simulation results. LUMOS is therefore a suitable alternative for non-image forming effect research in cases where expensive measurement equipment or other software solutions are not affordable or available. Since the program runs within MATLAB, it can be operated on Windows, Linux and MacOS without restrictions. The source code and program are freely available via an open-source licence.

Introduction

LUMOS [1] is a spectral radiosity simulation tool developed with MATLAB [2] for the calculation of the spectral light distribution in interiors. It utilizes the freely available Lighting Toolbox for MATLAB and Octave [3,4] to derive photopic and α-opic quantities from the spectral simulation data. The radiosity approach has the advantage that after the interior light distribution is calculated, any observer position inside the room geometry can easily be recalculated if changed, without the need to recalculate the whole room geometry. LUMOS includes a GUI and an editor, compare figure 1. It supports an arbitrary number of wavelengths and can model artificial lighting as well as daylight. It is openly available under BSD 3.0 licence. LUMOS was developed for lighting research applications and is intended to fulfill specific requirements. It was developed with the aim to:

- be cost effective.
- generate accurate spectral simulations.
- model artificial lighting and daylight.
- process an arbitrary spectral resolution.
- be easily scalable in accuracy.
- present spectral and spatial data.
- be modifiable.
- be easy to use.

LUMOS can be operated under all major operating systems, it is adaptable in terms of simulation accuracy, supports spectral data input with different wavelengths and can process spectral daylight measurement data. Users can also define their own spectral and spatial

daylight distributions if desired. Research facilities that already have a basic MATLAB license can use LUMOS without additional cost, no commercial MATLAB toolboxes are required.
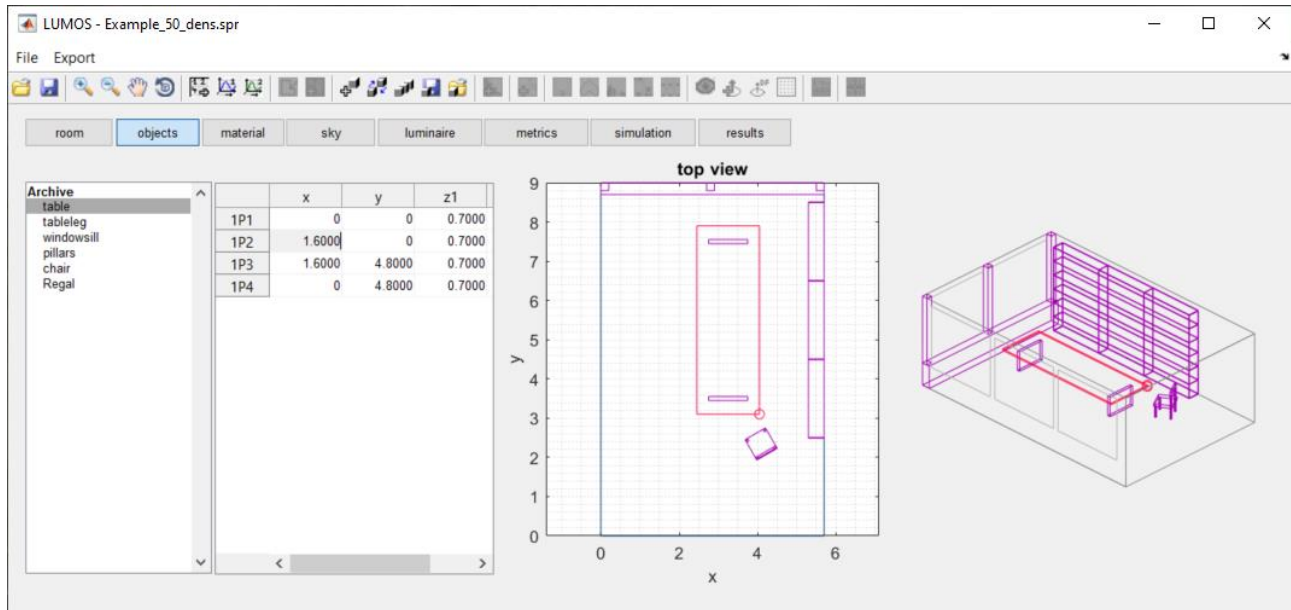

Figure 1: LUMOS GUI – Exemplary project, editing a table object.

Workflow

The workflow to create a simulation project in LUMOS is illustrated in figure 2. First the room geometry is generated and optional windows are added. In the next step the user can include polygonal objects inside the room geometry. All surfaces must then be applied with spectral reflectance data in `.txt` file format. For convenience purposes, LUMOS provides a library of common spectral material data [5]. In addition, artificial light sources and daylight data can be provided separately. For artificial lighting the luminous intensity distribution curve (LDC) is provided in EULUMDAT [6] `.ldt` file format, whereas the spectral power distribution of the luminaire is provided with a `.txt` file. Spectral power distributions of CIE standard illuminants [7,8] can be derived from the Lighting Toolbox for MATLAB and Octave. The spectral radiance of the sky dome is also given in `.txt` file format for 145 Tregenza sky patches [9]. For the evaluation of the light distribution, LUMOS can create calculation metrics, such as points and areas, as well as daylight factor (DF) points, which give the percentage of indoor daylight compared to unobstructed outdoor daylight [10]. Furthermore, spatial evaluation in observer position can be achieved with hyperspectral fisheye images in arbitrary viewing directions. The user can independently set the simulation's geometry patch density per square meter, the number of inter-reflections for each simulation and the north angle in the simulation settings. Figure 3 illustrates the different stages of the LUMOS simulation, starting with the wireframe and surface mesh and resulting in the light distribution and RGB rendering.

LUMOS was created with the intention to be user friendly. Projects can be saved and loaded, including the simulation results. The room geometries can be duplicated e.g. to easily evaluate the light distribution under different luminaires. Several objects can be merged into a

new object, as well as exported and imported for use in other LUMOS projects, including spectral material reflectance data. All data tables and illustrations in each workflow tab can be exported as Excel or `.png` file, compare the example illustrations in figures 3-5.
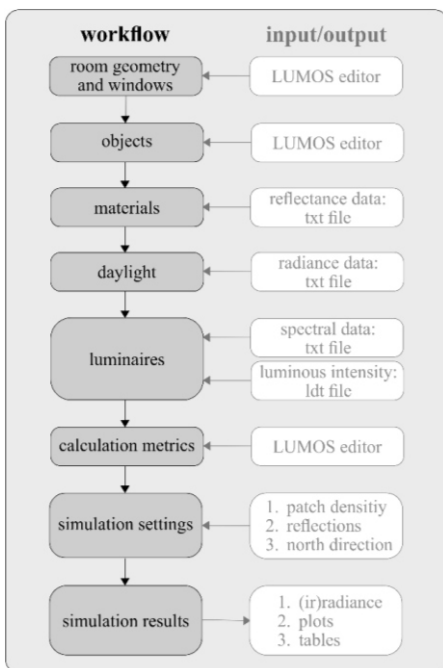

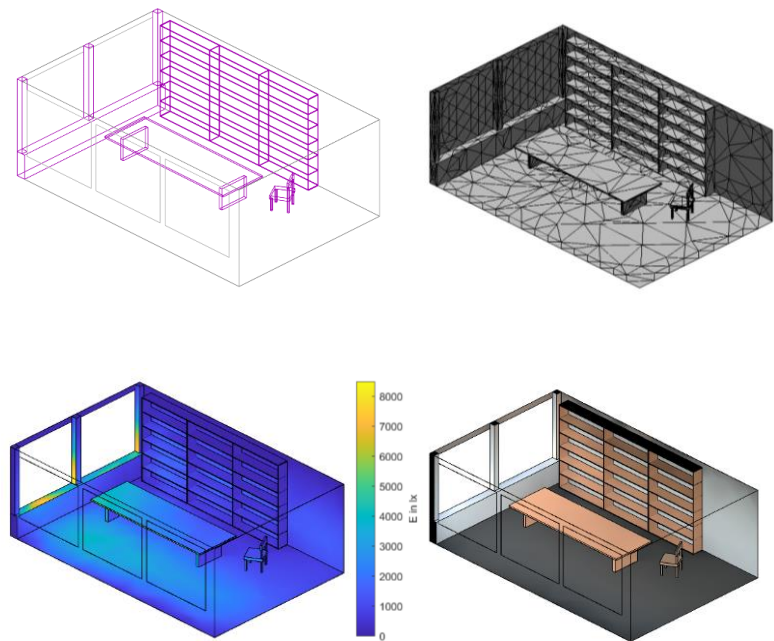Figure 2: LUMOS workflow including data input/output diagram.

Figure 3: LUMOS exemplary simulation stages: wireframe geometry illustration (top left), surface mesh illustration (top right), resulting illuminance false colour representation (bottom left) and resulting RGB room rendering (bottom right).

Simulation results

1.1   Spectral and spatial data representation

The simulation results of all surfaces and calculation objects can be examined after the simulation. For large surfaces, the user will easily get hundreds of grid points with spectral data. To illustrate this data in a meaningful manner, it is not advisable to plot all spectra on top of each other in a single illustration.

LUMOS provides different types of comprehensive illustration forms to present a wide range of spectra in a single figure, depending on the number of spectra. For several hundred spectra, an illustration of the spectral variation is most useful. This illustration form is provided under the *"(ir)radiance / (il)luminance"* result fields. It consists of the mean values, standard deviation (SD) and maximum and minimum values, compare figure 4. Next to the mean spectral power, the figure shows the magnitude of the data variation. A small SD area indicates similar spectral power distribution amongst the data points, while a large SD area indicates a broader variation. Large minimum or maximum areas indicate single outliers. This illustration form does not allow the user to draw conclusions on a single spectrum, but can in theory contain an unlimited number of spectra. An alternative illustration form is given by concatenated spectral slices in which the spectral power distribution is presented in false

colours. This illustration form is provided under the *"(ir)radiance spectra"* result fields. Each horizontal slice represents the spectrum of a single calculation point. In sum the spectral slices give an overview of the spectral distribution on the surface. This illustration form is limited in terms of presentable number of spectra, compare figure 4, where the spectral irradiance data of 25 calculation points is presented in both ways. LUMOS offers furthermore α-opic spatial evaluation with arbitrary viewing direction in any position, compare figure 5. This illustration form is given under the *"observer"* result fields, if any observer was added to the project by the user.
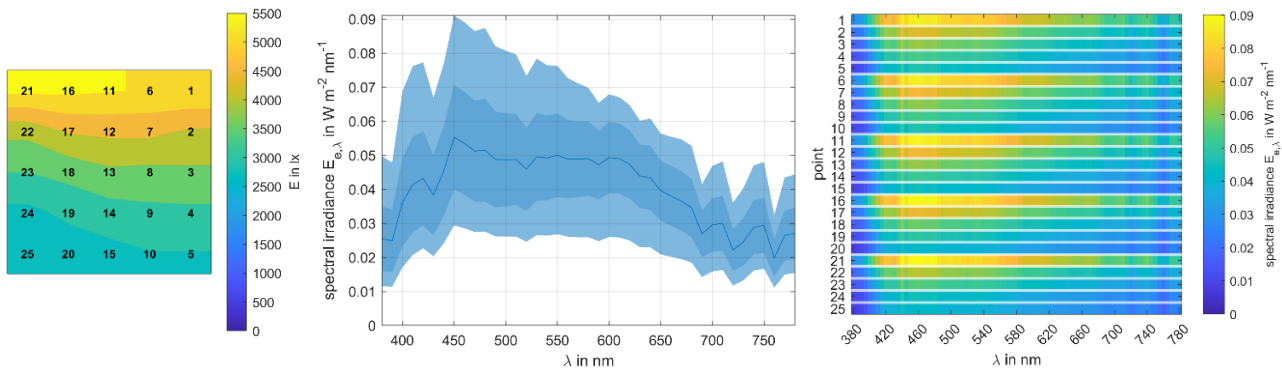

Figure 4: Spectral data representation of 25 calculation points – illuminance distribution on surface (left) with 25 calculation points, variation plot of the 25 calculation points spectra (middle) with mean value (blue line), standard deviation (dark area) and minimum and maximum values (bright area) and spectral slices of the 25 calculation points in false-colours (right).
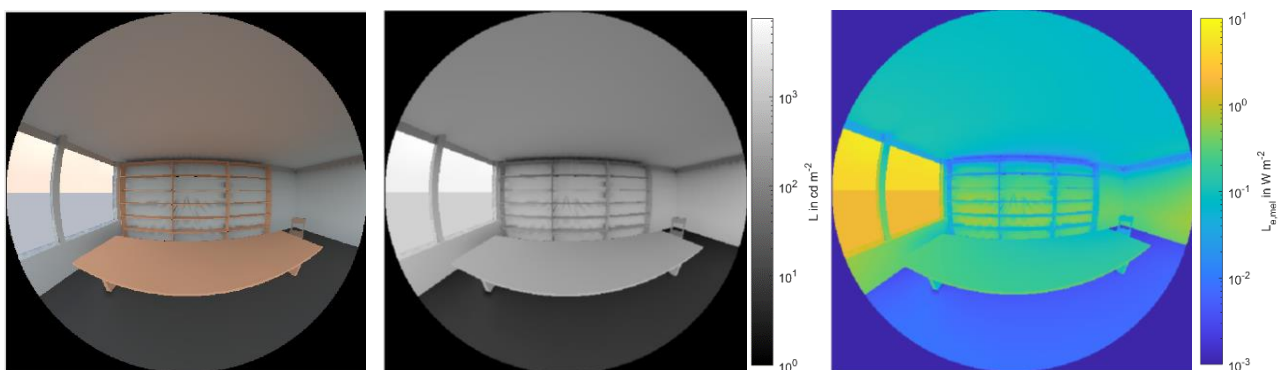

Figure 5: Fisheye RGB observer view (left), fisheye luminance observer view in grayscales (middle) and fisheye melanopic radiance observer view in false colours (right).

1.2 Simulation accuracy

To assess the accuracy of LUMOS, the software was tested in standard settings against the test scenarios described in CIE TR 171 [11]. Of the 25 CIE test scenarios, 21 were tested with LUMOS [12]. The results for the six experimental test scenarios all lie within the allowed error range. The mean absolute error (MAE) of the 15 applicable analytical test scenarios amounted to 0.56% with a SD of 0.80% for $n = 1894$ values. The minimum error was 0.00% and the maximum error was 15.34%. This high error occurred in a single point in a test scenario which addresses area light sources (test scenario 5.3). All other test point results lie below an error of 6%. [12]. Due to LUMOS still being under development, test scenarios with outdoor obstructions are not applicable yet and could therefore not be tested.

Strength and limitations

LUMOS enables users to create, simulate, analyse and represent spectral light distributions in interiors in a single processing chain. In combination with the complementary Lighting Toolbox for MATLAB and Octave, it allows for a more in-depth analysis of simulation results, e.g. by evaluating the α-opic weighted spectral radiance of the left and right eye, or the overlapping binocular field of view separately, compare figure 6. This modularity makes it a flexible, but highly performant software tool for non-image forming effects research. The program is available via open-source MATLAB code, allowing researchers to modify the code for their own needs.
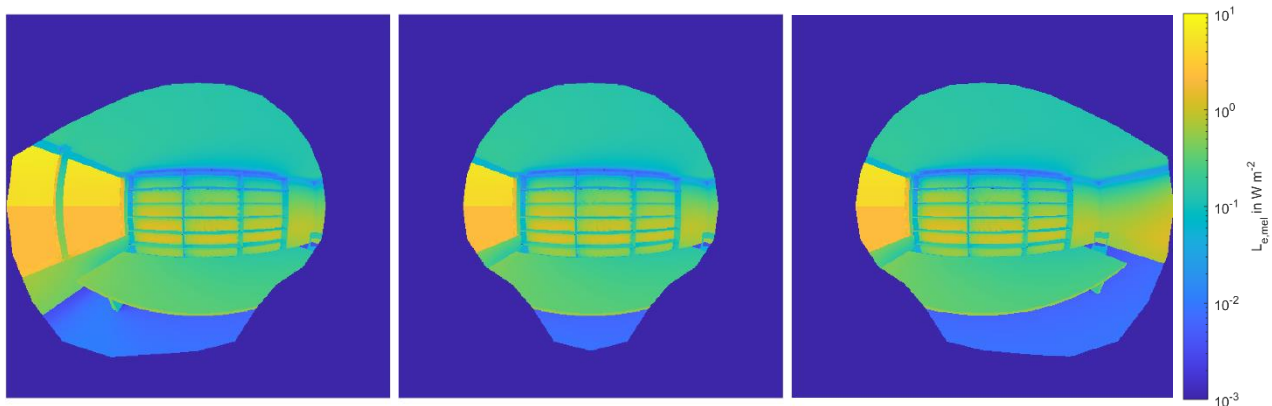

Figure 6: Exemplary evaluation of the field of view - melanopic weighted radiance: left eye (left), binocular overlap (middle) and right eye (right).

Next to the aforementioned restrictions concerning outdoor obstructions, the extensive advantages of the radiosity methodology are not yet fully implemented in LUMOS. At the moment, changes in the observer position lead to a complete recalculation of the entire scene. Furthermore, only the spectral radiance of the sky dome is currently considered in the simulation, disregarding direct sun radiation. However, these functionalities can easily be implemented in future releases and are currently being worked on.

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