Hybrid Ray Tracing

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The increasing complexity of optical systems combined with the demand for high optical efficiency and high image quality leads to the fact that the conventional use of ray tracing methods reaches its limits in the development of these systems. This challenge can be met by using a hybrid ray tracing method.

1 Motivation

In the field of optical engineering, optical systems are predominantly designed using sequential and non-sequential ray tracing. The decision when to use one of these ray tracing methods depends essentially on the later field of application of the system. Imaging optical systems are usually designed using sequential ray tracing, which allows an evaluation of the imaging quality and fast optimization of the design. Non-sequential ray tracing is primarily used to create illumination optics and allows, taking into account absorption losses and Fresnel reflection, an evaluation of the optical efficiency of the optics design.

Since today in several applications (e.g. high-resolution vehicle headlamps) optical systems with both illuminating and imaging characteristics are applied [1], [2], the conventional approach, using either sequential or non-sequential ray tracing, reaches its limits in the design of these systems. To meet this challenge, we propose to couple sequential and non-sequential ray tracing with the objective to combine the strengths of both ray tracing methods in a hybrid ray tracing method.

2 Concept of a hybrid ray tracing method

The basic concept (**Fig. 1**) of the hybrid ray tracing method is a stepwise optimization of the optics design using sequential ray tracing by means of the optical efficiency determined within non-sequential ray tracing. Starting with sequential ray tracing, first the optics design is created, optimized and evaluated with respect to the image quality. If the requirements of the image quality are met, the optics design is then transferred to non-sequential ray tracing via a script interface.

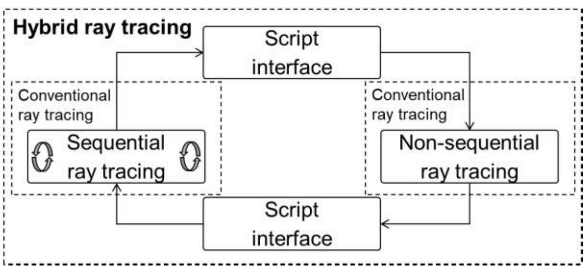

Fig. 1 *Concept of a hybrid ray tracing method [3]*

Taking into account the radiation properties of the light source, absorption losses and Fresnel reflection, the efficiency of the optics design is determined within non-sequential ray tracing. Subsequently, the determined efficiency is provided to sequential ray tracing via the script interface and used as an additional criterion to optimize the optics design in a further optimization loop. During re-optimization of the optics design, the previously determined efficiency is assumed to be constant. Following re-optimization, the image quality can again be evaluated as well as the optical efficiency by transferring the optics design to non-sequential ray tracing. This procedure will be repeated until the requirements for image quality and optical efficiency are met or a compromise between both requirements is found.

3 Implementation of a hybrid ray tracing method

Due to the wide distribution in industry and science as well as the performance and scope (sequential and non-sequential ray tracing) we decided to use Zemax OpticStudio® as optics simulation software to implement the hybrid ray tracing method. The optimization of the optics design within sequential ray tracing requires the initial definition of parameters and restrictions as well as the formulation of a merit function. As an expression of design goals to attain and to fulfill, the merit function can be executed as a standard or user-defined function using the comprehensive catalog of different operands. In addition, Zemax Programming Language (ZPL) enables the implementation of flexible user-defined programs (ZPL macros), e.g. to perform calculations based on Zemax data and return them to the merit function to optimize the optics design.

The script interface of sequential and non-sequential ray tracing of Zemax OpticStudio® is implemented using the open source software Python™. This is especially due to the toolbox "Python Zemax Dynamic Data Exchange" (PyZDDE) [4], which provides access to all functions of Zemax OpticStudio® including the execution of ZPL macros using the messaging protocol DDE. Furthermore, the tool Pyinstaller [5] offers the opportunity to bundle a Python application including its dependencies in a package and thus run the application without installing a Python interpreter. Thus a high portability

DGaO-Proceedings 2020– *http://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2020-B028-6

submitted: 23.Jun.2020 published: 8.Jul.2020

and almost system-independent execution of the application can be realized.

4 Hybrid ray tracing method within the Opti² tool

Using Zemax OpticStudio® for optics simulation and Python™ for script interfacing, the Opti² tool [6] was implemented for semi-automated optimization of optics designs based on the hybrid ray tracing method. Within the user interface of Opti² (**Fig. 2**), the *Zemax Functions* section allows the user to open Zemax OpticStudio® (①), open selected designs for sequential (②) and non-sequential ray tracing (③) and to save currently open optics designs (④). By executing the trace function (⑤), rays are traced through the optics design within non-sequential ray tracing. Once the rays have been traced, the detected luminous flux can be saved by the user (⑥). Using our self-written ZPL macro, the previously saved luminous flux value (representative of the optical efficiency) is then written into the merit function of sequential ray tracing as a design goal to attain or to fulfill. Within the *Optimization Settings* the user now has the opportunity to set the importance of the optical efficiency compared to other optimization criteria, such as image quality, by specifying a weight (⑦) and target value (⑧). Executing the optimization (⑨) will optimize the optics design within sequential ray tracing. This procedure can be repeated until the requirements for optical efficiency are met or a user-side termination is performed.

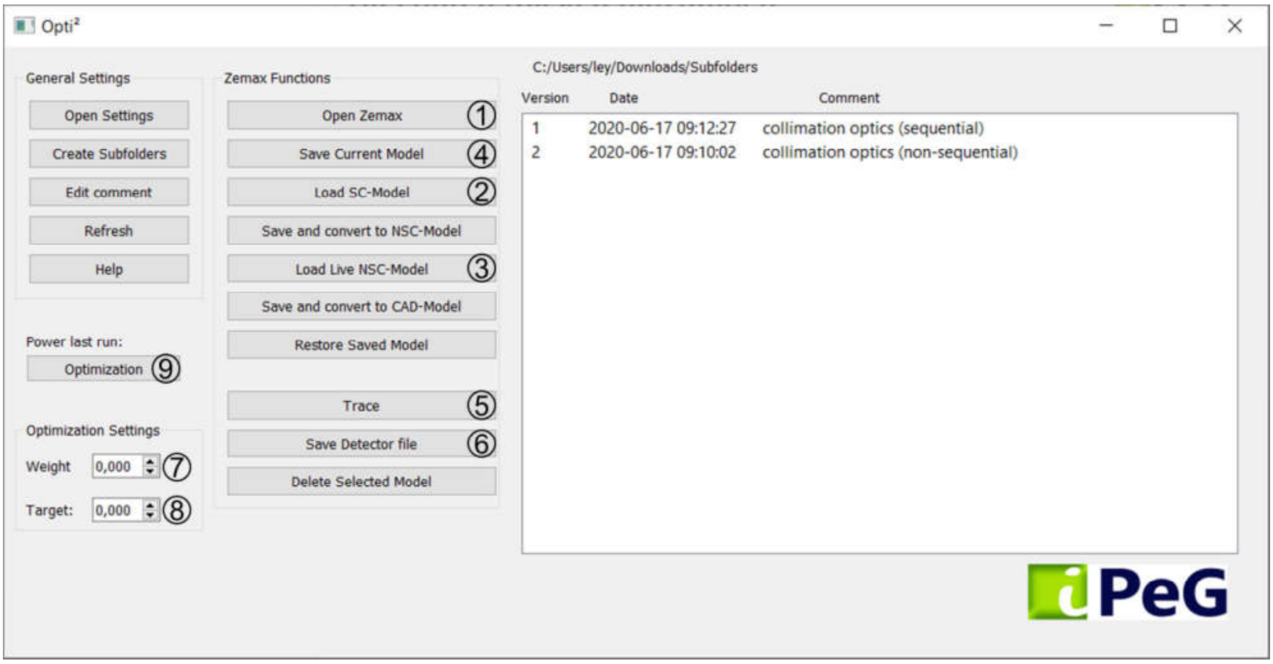

***Fig. 2** User interface of the Opti² tool [6]*

5 Conclusion

To validate the hybrid ray tracing method with respect to improve the optical efficiency compared to conventional methods, collimation optics were designed for an LED light source using conventional methods and the Opti² tool [3]. Comparing both efficiencies (**Tab. 1**) reveals that for this example an increase in efficiency of 3% could be achieved using the proposed hybrid ray tracing method. The applicability of the results to a multi-lens system must be clarified in future investigations.

***Tab. 1** Optical efficiencies of simulated collimation optics*

	Hybrid ray tracing lens	Conventional ray tracing lens
Optical efficiency	85.3%	82.2%

6 Acknowledgment

This project was funded by the Leibniz University Hannover within the internal university project funding "Wege in die Forschung".

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submitted: 23.Jun.2020 published: 8.Jul.2020