Machine Learning to Improve Illumination Optics Design

Team

The Department of Mathematics and Computer Science of Eindhoven University of Technology has a vacancy for a PhD-student in Computational Illumination Optics group, https://www.win.tue.nl/~martijna/Optics/. The Computational Illumination Optics group is working on design methodologies for non-imaging optics, imaging optics and on improved simulation tools for optical design.

Background

Illumination optics plays an important role in modern society. Products like mobile phones, lamps, car headlights, road lighting and even satellites all utilize illumination optics. A good optical design determines, for example, the energy efficiency of illumination devices, the minimization of light pollution or the sensitivity of sensors in satellites.
The design of novel, sophisticated optical systems requires advances in the mathematical description and numerical simulation methods for these systems.

Project description

Freeform optics, a branch of geometrical optics, is concerned with the design of optical surfaces, either reflectors or lenses, that convert a given source light distribution into a desired target distribution. An example, used in street lighting, is a single reflector that transforms the emittance of an LED source into an intensity distribution in the far field. The challenge in illumination optics is to find the reflectors or lenses that transfer a given energy distribution of the source into the energy distribution of the target. There are two approaches, *direct methods,* and *inverse* methods.

Direct methods

In direct methods an optical system is created in a CAD tool and the energy distribution is calculated using ray tracing.
The industrial standard simulation tools are based on Monte-Carlo ray tracing. A light ray is randomly started at the source, and applying the laws of reflection and refraction the path of the light ray is calculated, till it arrives at the target. On this target the energy distribution is reconstructed. To obtain a desired light distribution, an engineer needs to adjust the CAD geometry in multiple iterations till the engineer is satisfied with the obtained results.

The advantage of the Monte-Carlo ray tracing method is that it is easy to implement, can contain all kind of physical phenomena (absorption, scattering and Fresnel reflections), but the disadvantage is that it is slow; to improve the accuracy with a factor two, the number of rays needs to be increased by a factor four.
We have built a simulation tool that uses another description of the energy distribution based on Liouville's equation. This tool is two orders of magnitude faster or more accurate than state-of-the-art Monte-Carlo based ray tracing, and gives more details on the distribution of energy in phase space, see Figure 1.

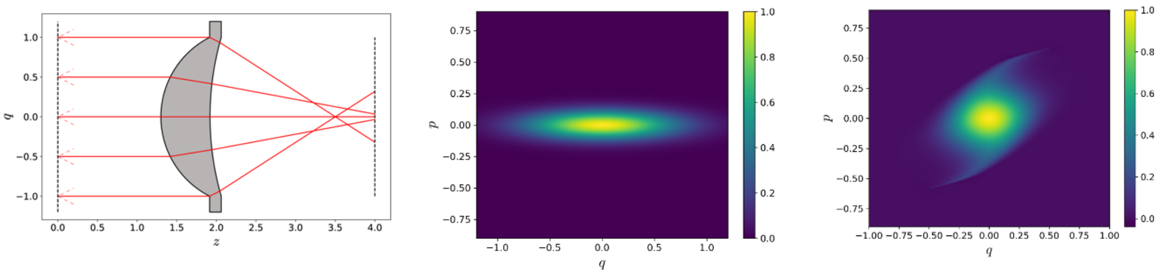

Figure 1. On the left a simple lens system. In the center the energy distribution on phase space at the object side and on the right the energy distribution in phase space on the target, image side, obtained by solving a Liouville equation.

Inverse methods

In inverse methods the shape of the lens or reflector is calculated directly by solving an appropriate partial differential equation, avoiding iterations and manual optimization. This is illustrated for a two-dimensional optical system in Figure 2. The goal is to find the shapes of the reflectors for given source and target light distributions.

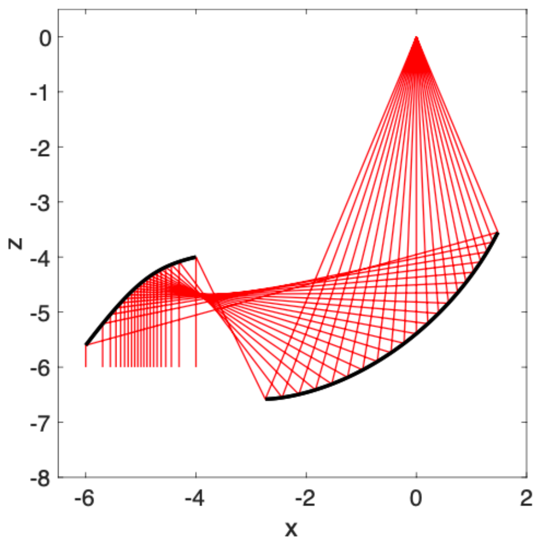

Figure 2: The two reflectors (black) convert a parallel beam of light starting at the source at $-6 \leq x \leq -4$, $z = 0$, into a point target at $x = 0, z = 0$. Note that the light distribution is Gaussian at the source and uniform at the target.

The governing laws are the principles of geometrical optics (law of reflection/refraction) and conservation of energy. Geometrical optics gives the optical map from source to target, and combined with energy conservation, this gives rise to the so-called Monge-Ampère equation, which is a second-order fully nonlinear partial differential equation.

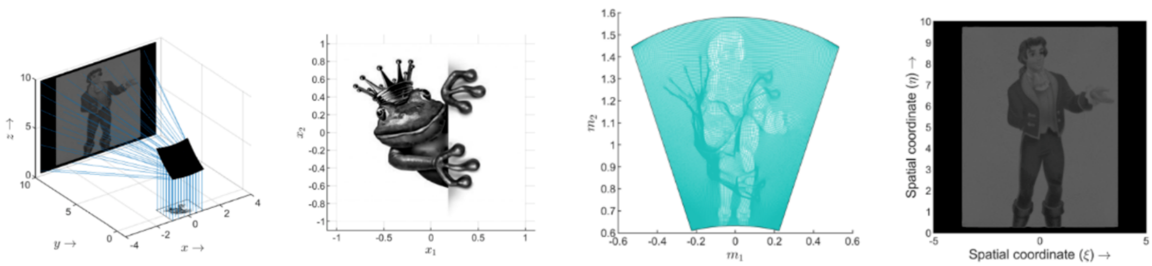

Figure 3. On the left a reflector that transforms the energy distribution of a frog to a prince. In the second picture we show the source distribution, in the third the optical map and in the last figure the results of a verification based on ray tracing: the system gives indeed the prince.

In recent years, we have developed tools to solve the Monge-Ampère equation for many optical systems. So, given the source and target energy distributions, we can calculate the optical geometry immediately, see Figure 3 where we have computed the surface of a reflector that transforms a frog into a prince.
The inverse tools are fast, but also have some limitations, e.g., the methods assume a perfect parallel source or an infinitesimal source dimension (point source). However, real sources have a finite size and are not perfectly parallel. In addition, effects like absorption, scattering and Fresnel reflections are not considered in the inverse design methodology.

To overcome the shortcomings of direct and inverse methods, we would like to take another approach in this project:

a) Use the available tool chain to build a training set that consists of source and target distributions and optical geometries.
b) Develop machine learning algorithms that can solve the inverse optical problem.

Tasks

As a PhD student your tasks are the following:

- Perform scientific research in the described domain.
- Present results at international conferences.
- Publish results in scientific journals.
- Participate in activities of the group and the department.
- Assist in teaching undergraduate and graduate courses.

Requirements

We are looking for talented, enthusiastic PhD candidates who meet the following requirements:

- An MSc in data science or computer science.
- Experience with applying and developing machine learning tools.
- Interest in numerical methods and physics problems.
- Experience with programming (C, C++, Python, Matlab or alike).
- Creative, pro-active team player with good analytical skills.
- Good communicative skills in English, both written and oral.

Appointment and salary

We offer:

- A full-time appointment for a period of four years, with an intermediate evaluation after nine months.
- A gross salary of 2,541 euro per month in the first year increasing up to 3,247 euro per month in the fourth year.
- Support for your personal development and career planning including courses, summer schools, conference visits, etc.
- A research position in an enthusiastic and internationally renowned research group.