Designing freeform optics for multiple source illumination with AI

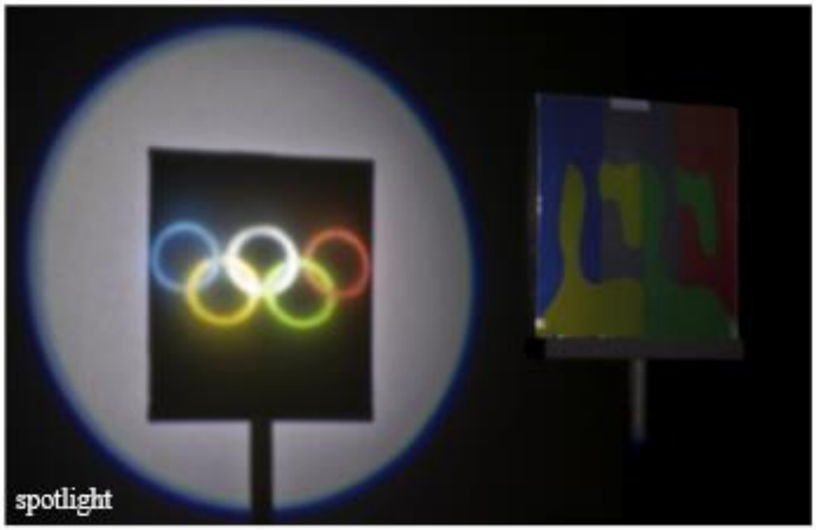

Figure 1 Freeform lens redirecting incoming light into the Olympic ring [1]

Project background

Contemporary lighting systems such as street- and theater lights are looking for ways to transport the light emitted by LED's into a target intensity distribution. To achieve this, freeform optical elements without any form of symmetry are used to control the light thanks to the geometry of the lens.

The forward problem, that is, the determination of the light distribution of a given freeform optic, can be solved using wave optics simulations [2] or ray tracing [3, 4]. The inverse problem consists of finding a freeform geometry that yields a desired light distribution is, however, rather complex and its solutions are often limited to very simple illumination configurations. The most common being a single monochromatic source. However, in applications such as street- and theater lights freeform optics are ideally designed for multiple-sources as this allows for higher light-throughput and color control.

This master project will investigate a novel approach for designing freeform optics for multiple source illumination. The two key technologies used in the project are *Non-Uniform Rotational B-Splines (NURBS)* to model freeform surfaces and *Physics Informed Neural Networks (PINN)* to solve the inverse problem.

NURBS [5] are the industry standard in Computer-Aided Design (CAD) tools and widely used in many engineering disciplines, where complex geometries need to be constructed with the aid of computers. NURBS allow for modeling arbitrarily complex freeform surfaces with the aid of a moderate set of control points, whose placement in the three-dimensional space defines the full shape of the freeform surface. Changes to individual control points lead to a continuous but local variation of the freeform surface, which makes it possible to carefully adjust the freeform object by optimizing the placement of control points.

PINNs [6] have been developed in the context of physical systems that are modeled by partial differential equations (PDEs). The core idea is to train a neural network in predicting solution values to PDE problems and complementing boundary conditions by penalizing deviations from the differential equation or the boundary conditions in the loss functions. The major advantage of PINNs over classical AI solutions is that no training data needs to be pre-generated since the quality of predictions during the training process can be determined in unsupervised manner by measuring the deviation from the PDE/boundary value.

Our AI-based approach to design freeform optics combines NURBS and PINNs in the following way: The surface of the freeform optics is modeled by NURBS and a neural network is trained in predicting the optimal placement of the control points. 'Optimal' is to be understood in the sense that the light intensity distribution that results from the generated freeform optics deviates only minimally from the prescribed target distribution. This deviation is quantified (and penalized) via the neural network's loss function, whereby wave optics simulations and/or ray tracing (forward problem) is used to generate the intensity distribution. At a later stage of the project, also the position of the multiple illumination sources can become output parameters of the network that are optimized with the help of AI.

The project will consist of the following tasks:

- Literature study on fundamentals of NURBS and PINN
- Implementation of a first version of the AI-based approach for freeform optics design using one of the established AI software frameworks (e.g. TensorFlow or PyTorch) with fixed illumination sources
- Acceleration of the training process using GPU computing. This might also include the use of a CUDA-accelerated ray tracing simulation of the forward problem.
- Testing and adjustment of the AI-based approach for selected benchmark cases.
- Optional: extension of the AI-based approach to also optimize the position of the illumination sources and validation for benchmark cases.

This master project is carried out in collaboration with the Optics Group at the Faculty of Applied Physics (contact Dr. A. Adam, A.J.L.Adam@tudelft.nl), who are experts in freeform optics design and currently working on the application to this method with industrial partners (Signify, TNO). This collaboration makes it possible to perform an experimental validation of the obtained results. Upon request preliminary research of a bachelor student can be shared for additional information.

If you are interested in this master project and/or have further questions please contact Dr. M. Möller, M.Moller@tudelft.nl.

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