Differentiable ray tracing for solar simulator Synlight

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How much light will reach my experiment? This is one of the crucial questions when working with a solar simulator like Synlight in Juelich, which often ended up only vaguely answered. This is because the currently available models for the flux distribution prediction do not provide an accuracy required for the design phase of a solar reactor or receiver [1]. These issues stem from various sources, but most notably from deformation of reflectors, likely caused by their own weight and heat. One potential way to improve the situation is a more accurate modelling of the inaccuracies through differentiable raytracing, which is being worked on in this PhD thesis.

The first main task of this approach is to use flux measurements to reconstruct reflector or the misalignment of the light source by deriving optical parameters from the measurement data. To solve this inverse task a gradient (in the direction of the deformations) comparing the measurement with the equivalent data of the ray tracing simulation was built. By constantly comparing this gradient, it is now possible to determine precise deformation parameters for the simulation, ultimately reconstructing the same flux distribution as in the measurement. In order to calculate this gradient, a differentiable raytracer for Synlight needed to be built, which introduced a set of new and interesting challenges.

If a general differentiable ray tracing method is used, as is more common in computer graphics, a major challenge is the seeming discontinuity in ray paths, as they either hit an object, or not. This makes ray tracing not differentiable by applying automatic differentiation [2] without regards to geometry. This was solved for many general problems by various methods, such as sampling the gradient along ray paths that intersect with these edges [3]. Still, these methods are a field that is being very actively researched, and remain difficult to implement, often taking assumptions that are not applicable in cases like the Synlight ray tracing. Thus, investigating more constrained problems remains a worthwhile task. This can be done by developing a method avoiding geometry boundaries, while still resulting in a suitable gradient, and implementing it in a differentiable ray tracer. Using the gradients produced by the ray tracer, it can then be demonstrated that deformations from measurements can be reconstructed using gradient-based optimization techniques. After this, results from the raytracing software can be compared to flux measurements to evaluate the accuracy of the software built.

To draw a conclusion, a short outlook over further planned developments in the project will be given. These most importantly include scenarios modelling multiple lamps simultaneously. On top of that, generalization ideas of the model to expand its applicability to further facilities will be presented.

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