Supplemental Document

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Fast Sensitivity Control Method with Differentiable Optics

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1. Details about the differentiable optics model in Section 2.1

Differentiable ray tracing

The initial Rays are uniformly sampled on the entrance pupil according to the vignetting coefficient. And the subsequent The ray tracing process involves two sequential steps for each surface: 1) solving for the intersection point between the incident ray and the surface, and 2) updating the direction cosines of the refracted ray according to Snell's law.

During propagation, rays undergo three validity checks: confirming the intersection solution, ensuring the intersection occurs within the surface's aperture, and verifying that no total internal reflection occurs.

Additionally, we record all relevant data during ray propagation to compute the optical constraint terms in the loss functions.

Coherent PSF [1]

We developed a differentiable coherent PSF model in which rays are coherently summed as plane waves to form the complex amplitude. Each ray represents a plane wave originating from a field point, interacting with the optical system, and propagating to the image plane. We accumulate the optical path length of each ray from the field point to the image plane

$$OPL = \int_{field\ point}^{image\ plane} n(\lambda)\ ds,$$

where we use dispersion models consistent with Zemax material catlalogs (e.g., Schott, Sellmeier, etc.) to retrieve the refractive index at any wavelength.

As shown in Fig. S1, for the sampled grid points on the image plane, the complex amplitude distribution is obtained by coherently summing the complex field contributions of plane waves represented by each ray

$$A(x,y) = \sum_i a_i e^{ikOPL_i + \Delta r_i(x,y)} < \vec{n},\vec{d} >$$

where $A(x,y)$ is the complex amplitude at the grid point (x,y), a_i is the amplitude of the i-th ray, k is the wave number, $\Delta r_i(x,y)$ denotes the optical path length of the i-th ray to the grid point (x,y), and $< \vec{n},\vec{d} >$ is the inner product of image plane normal and the cosine of the ray direction. The PSF represents the intensity captured on the detector, is calculated by

$$PSF(x,y) = A(x,y)A^*(x,y)$$

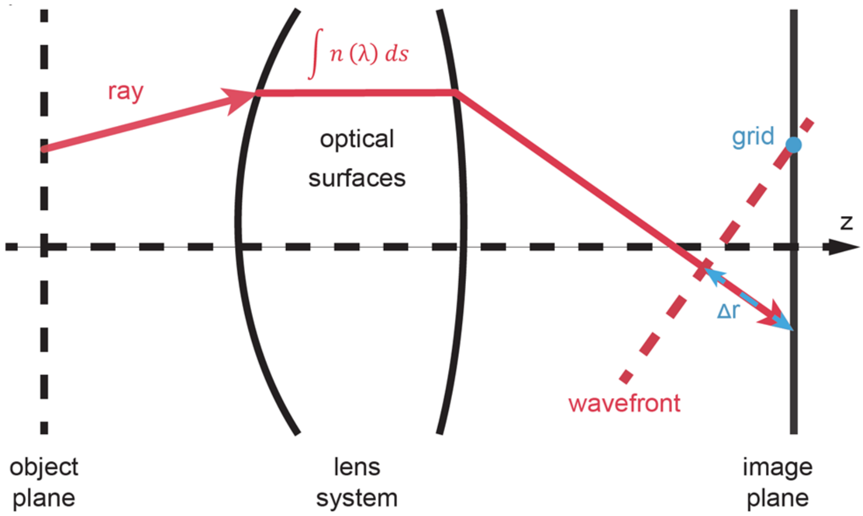

Figure S1: Schematic diagram of the coherent PSF calculation process

Reference

[1] Ren Z, Zhou J, Zhang W, et al. Successive optimization of optics and post-processing with differentiable coherent PSF operator and field information[J]. arXiv preprint arXiv:2412.14603, 2024.