Optics in 2024

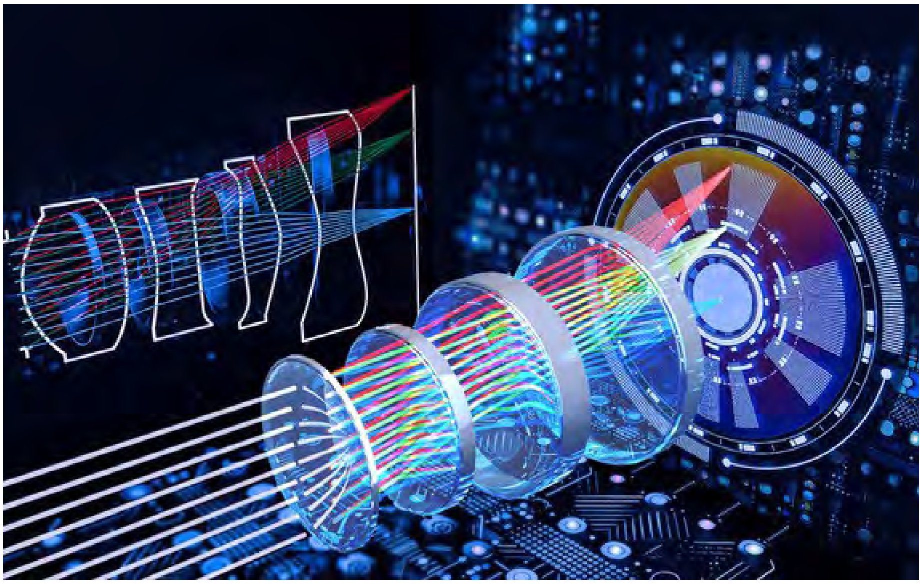
An AI Curriculum for Learning Lens Design

Optical lens design has traditionally relied on incrementally improving and combining existing designs in a largely manual process. Automated optimization strategies typically fail to discover superior solutions far from the starting configuration due to local minima in the optimization landscape, while simultaneously avoiding degenerate or non-physical geometries. This inability to automatically discover new designs is particularly limiting in the design of computational imaging systems, where the complex interactions between optical design and algorithmic processing defy classical heuristics and intuitions.

In work published this year,[1] we introduced a fully automated lens design algorithm that uses deep optics[2] and differentiable ray tracing.[3,4] Starting from flat surfaces, our DeepLens method can autonomously achieve a lens design with competitive optical objectives, particularly in terms of the root-mean-square value of ray spots. To avoid local minima and degenerate configurations, we developed a dedicated curriculum learning approach for lens design. Like a teacher developing a curriculum for a complicated subject that exposes the pupil to concepts of increasing complexity, we break down the lens design task into milestones of increasing difficulty and complexity. The optimization process strategically increases aperture size and field of view (FoV) to navigate away from local minima in the optimization space. Additionally, several optical regularization terms are incorporated to prevent degenerate lens geometries, such as self-intersections.

Beyond classical lens design, our work also showcases an extended depth-of-field (EDoF) lens. Several memory-control strategies are proposed to support high-resolution image simulation and end-to-end optimization of the lens and network. Simulation results demonstrate promising imaging quality across a broad depth range, from 10 cm to 10 m. Notably, this marks the first demonstration of an EDoF lens with a compact form factor, large FoV, and small F-number, promising advances for future mobile camera technology.

Our work highlights the potential of deep learning and artificial intelligence in optical design, particularly for refractive optics systems where light propagation can be accurately modeled with ray optics. Building on these findings, an open-source optical design framework[5] has been established. DeepLens empowers users to create and optimize their optical systems using deep learning, offering full control over the optimization process. Leveraging the exceptional optimization capabilities of deep-learning algorithms and GPU acceleration, our work opens the door for the next generation of optical design. OPN



The DeepLens design method is highly effective in automatically designing both classical optical designs and an extended depth-of-field computational lens. © 2024 KAUST.

RESEARCHERS

Wolfgang Heidrich (wolfgang.heidrich@kaust.edu.sa), **Xinge Yang** and **Qiang Fu**, King Abdullah University of Science & Technology, Saudi Arabia

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