3D Visualization of Optical Ray Aberration and Its Broadcasting to Smartphones by Ray Aberration Generator

Brandon Hellman[1], (alphabetically) Erica Bosset[1], Luke Ender[1,2], Naveed Jafari[1,3], Phillip McCann[1], Chris Nguyen[1], Chris Summitt[1], Sunglin Wang[1], Yuzuru Takashima[1]

[1] *University of Arizona, 1630 E University Blvd, Tucson AZ, hellman@email.arizona.edu;*
[2] *Whitworth University, Spokane WA;*
[3] *University of New Mexico, Albuquerque NM*

Abstract: The ray formalism is critical to understanding light propagation, yet current pedagogy relies on inadequate 2D representations. We present a visualization system which propagates real light rays through an optical system, and an implementation for remote, immersive access.

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1. Introduction

The ray is a conceptual representation of the path along which electromagnetic energy propagates, and is essential to the language of the imaging and optical system design community. Rays propagated through optical systems offer an extremely rich basis of information [1]. For example, tracing rays through a 30-element lithographic lens will show an extremely smooth flow. Optical design experts recognize how a smooth flow of rays is crucial to minimizing aberrations. In practice, observing ray trajectories and relating the information to system performance is the foundation of optical system design.

Although experts in the lens design community understand the importance of the ray, methods to demonstrate and visualize ray propagation through optical systems have not been fully investigated, especially for educational purposes. Textbooks and simulated renderings are available teaching resources, though real-world demos are lacking.

In particle physics in 1911, C. T. R. Wilson presented a method to visualize alpha and beta particles by condensing water on the particles within a water-vapor-filled "cloud-chamber" [2]. By a similar "cloud-chamber" technique, we present a system which allows the visualization of light rays propagating through an optical system.

2. Visualization and Control of Rays

The Ray Aberration Generator (RAG) is a teaching tool to demonstrate ray propagation and real-world manifestations of third-order aberrations, including spherical aberration, coma, astigmatism, field curvature, and distortion.

Multiple, independent light beams, sourced from either a laser through a grating or a handheld projector, act as rays being traced through a system. The rays are coupled into a fog-filled tank containing a lens. As each ray propagates through the tank, light is scattered by the fog which allows visualization of each ray path. The material of the lens is imperfect, causing scatter as the ray propagates through the lens, allowing visualization of the ray path within the lens itself. The entire path of each ray can be visualized from the entrance surface to the final image plane. The left image in Fig. 1 shows the sources (bottom) coupling into the tank (top) by the mirrors (left).

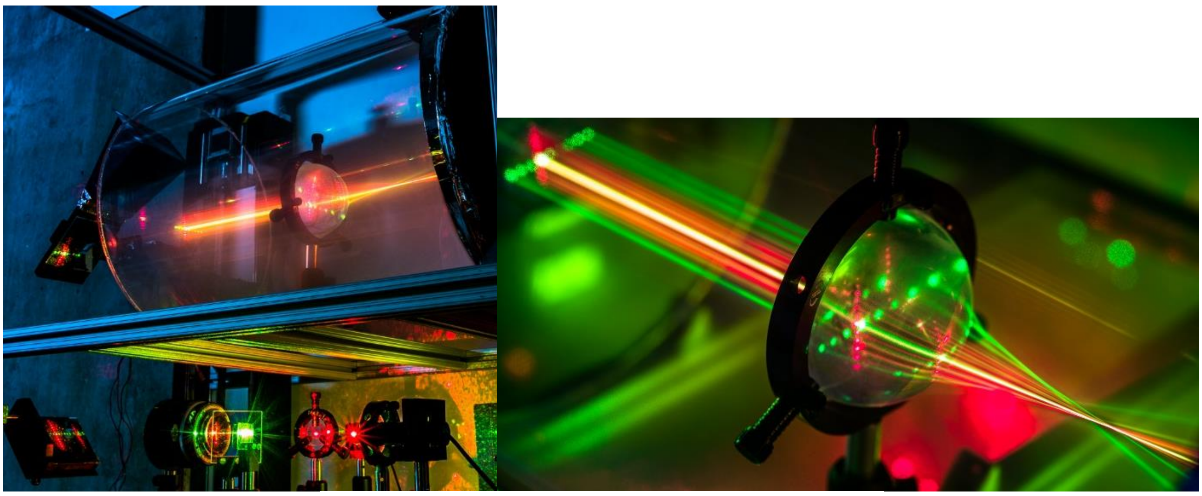

Fig. 1: RAG Platform (left) and Ray Tracing (right)

The lens, which is interchangeable, has set aberrations due to the surface shapes. To view different ray effects of the third order aberrations, the input ray trajectories can be adjusted through software controlling a motorized input coupling mechanism. The system has control of both field height and pupil coordinate.

3. Real-World Ray Trace

The array of collimated beams is a very effective ray trace due to the small beam diameter and pitch. Though some spreading of an individual beam may occur due, Fig. 2 shows how the injected beams match the simulated rays.

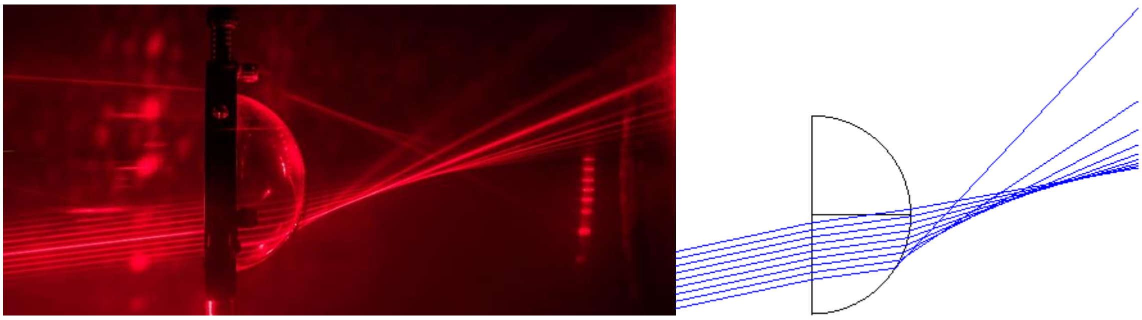

Fig. 2: RAG (left) comparison to Zemax model (right)

4. Remote Access

The system is not portable, but a method was developed to grant students around the world access to the RAG. A robotic arm with a stereoscopic camera captures a 3D video to stream to a smartphone. Using Google Cardboard, a do-it-yourself cardboard headset which turns a smartphone into a virtual reality display, remote users can view the 3D demo live. Head gesturing in an Android app sends accelerometer data back to the robotic arm, moving the camera accordingly. The head gesturing, which causes live perspective shifting, creates a more immersive 3D experience.

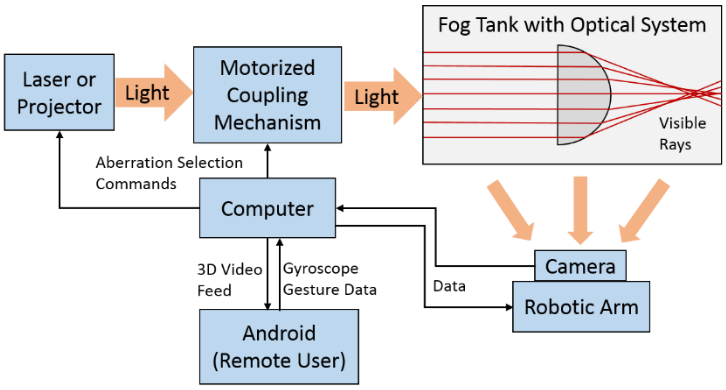

Fig. 3: RAG Block Diagram

5. Conclusion

The Ray Aberration Generator offers a new real-world platform to demonstrate ray propagation and aberrations using real light rays. The interchangeable optical system, programmable input rays, and immersive remote access offer extensive capabilities to help students visualize and understand light ray propagation.

6. References

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