Homework 4 - Introduction to Computational Optics

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Exercise 1: Refining Phase Distribution Using the GS Algorithm

Problem Overview

In this exercise, the goal is to refine a phase distribution generated using geometrical optics to better account for diffraction effects. This is achieved through the implementation of the Gerchberg-Saxton (GS) algorithm, a widely used iterative method for phase retrieval. The algorithm modifies the phase distribution iteratively while preserving target amplitude constraints in both spatial and Fourier domains.

Methodology

1. **Initial Phase Estimation:** The initial phase distribution, $\phi(x, y)$, is combined with a uniform amplitude to form the complex field:

$$U(x, y) = A(x, y)e^{j\phi(x,y)}.$$

2. **Forward Propagation:** The field is propagated to the target plane using the Angular Spectrum Method (ASM):

$$U'(x', y', z) = \mathcal{F}^{-1}\left[H(f_x, f_y, z) \cdot \mathcal{F}\{U(x, y)\}\right],$$

   where $H(f_x, f_y, z)$ is the transfer function accounting for wave propagation.

3. **Amplitude Constraint:** The amplitude of the propagated field is replaced with the target amplitude while preserving the phase:

$$U'(x', y', z) = A_{\text{target}}(x', y')e^{j\phi'(x',y',z)}.$$

4. **Backward Propagation:** The modified field is propagated back to the original plane by reversing the propagation distance ($z \to -z$).

5. **Iterative Refinement:** Steps 2–4 are repeated until the computed irradiance matches the target distribution within a specified tolerance.

Results and Observations

The GS algorithm significantly improves the fidelity of the phase distribution by minimizing the deviation between the simulated and target irradiance. The iterative nature of the method ensures convergence, though the speed and accuracy can vary depending on the initialization and propagation parameters.

Applications

This refinement process is particularly valuable in designing Diffractive Optical Elements (DOEs) for applications such as:

- Beam shaping in laser systems.
- Holographic imaging.
- Structured light generation for optical metrology.

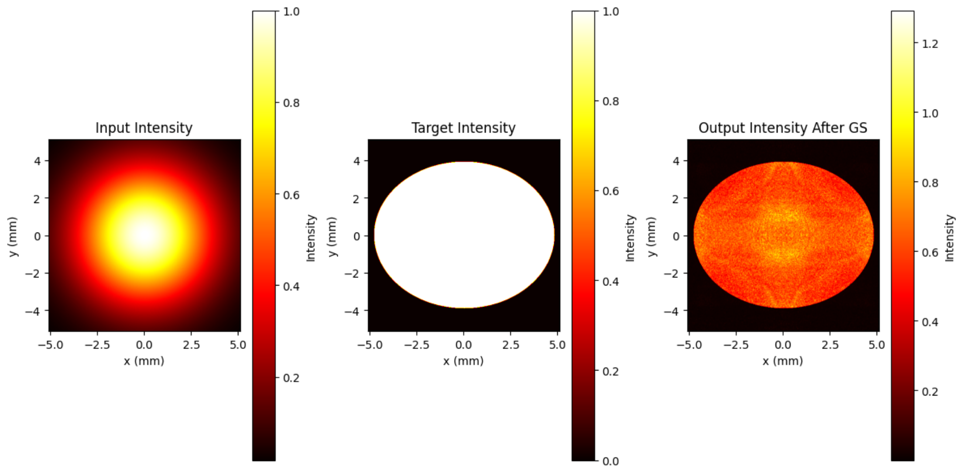

Figure 1: Schematic of Applications for DOEs, Freeform Lenses, and Metasurfaces.

Exercise 2: Comparison of DOEs, Freeform Lenses, and Metasurfaces

Introduction

In modern optics, Diffractive Optical Elements (DOEs), freeform lenses, and metasurfaces have emerged as powerful tools for manipulating light. While each technology is effective in specific contexts, their unique strengths and limitations shape their applications. This comparison aims to provide a practical perspective on these technologies based on their use in imaging and non-imaging applications.

Overview

Table 1 summarizes the key characteristics of the three technologies, which will be discussed in detail below.

lightgray **Technology**	**Key Advantages**	**Key Limitations**
DOEs	Cost-effective and efficient for specific wavelengths.	Limited broadband and chromatic performance.
Freeform Lenses	Highly customizable, excellent control over wavefronts.	Expensive and complex to manufacture.
Metasurfaces	Extremely thin and integrable into compact systems.	High production costs; challenges in scaling.

Table 1: Summary of Key Features of DOEs, Freeform Lenses, and Metasurfaces.

Detailed Comparison

Diffractive Optical Elements (DOEs) manipulate light through diffraction using a structured surface to shape phase or intensity profiles.

- **Strengths:** Cost-effective, efficient for monochromatic light, widely used in laser shaping.
- **Weaknesses:** Chromatic aberrations, fabrication complexity for multilevel designs.

Freeform Lenses deviate from traditional symmetric designs, offering tailored solutions for advanced optical applications.

- **Strengths:** High customizability, exceptional broadband performance, precise wavefront control.
- **Weaknesses:** High cost, complex manufacturing processes.

Metasurfaces consist of nanostructures that manipulate light on a subwavelength scale, enabling unprecedented functionalities.

- **Strengths:** Miniaturization, polarization control, versatile applications in photonics.
- **Weaknesses:** High production costs, scalability challenges.

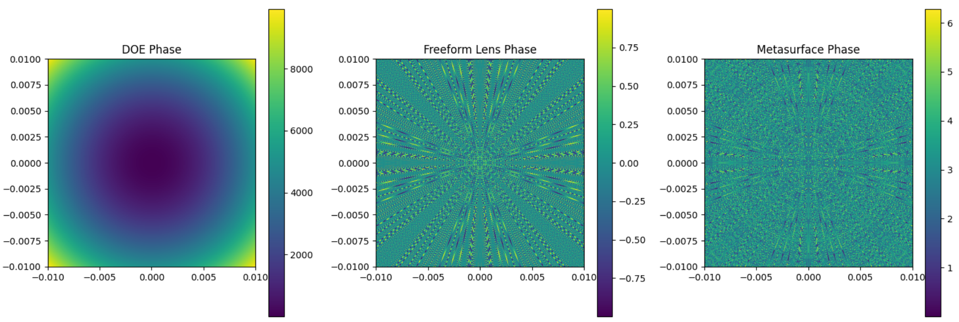

Figure 2: Comparative Applications of DOEs, Freeform Lenses, and Metasurfaces.

Conclusion

The choice of optical technology depends heavily on the application:

- DOEs are ideal for cost-effective monochromatic tasks.
- Freeform lenses are suited for high-precision, broadband applications.
- Metasurfaces excel in compact systems, though they face scalability challenges.

References

1. Banerji, S., et al., "Imaging with flat optics: metalenses or diffractive lenses?" *Optica*, 2019.
2. Engelberg, J., and Levy, U., "The advantages of metalenses over diffractive lenses," *Nature Communications*, 2020.
3. Liao, Q., et al., "Differentiable design of freeform diffractive optical elements for beam shaping," *Optics Express*, 2024.