End-to-end optimization of coded aperture for extended depth of field

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1 Introduction

Deep optics by combining optics and post-processing methods provides a new pathway towards optimizing images, compared with the traditional purely image post-processing pipelines or only lens optimization. Such end-to-end optimization can be applied to a variety of applications including extended depth of view, de-blur, and super-resolution imaging. In this study, we would like to apply the end-to-end framework to optimize the coded aperture for extended depth of field along with the image processing.

2 Motivation

The study by V. Sitzmann et al optimizes the geometry of the optical lens along with the image processing, where the tuning of point spread function of the optical system is achieved by chaning the phase response of the lens. However, the optimized lens geometries, which require diamond turning or photo-lithography for fabrication, are costly and challenging for massive manufacturing.

On the other hand, point spread function tuning can also be achieved through changing the amplitude response, i.e. tuning the transparency of the aperture. Therefore, in principle, we can optimize the transmission of the aperture, basically a gray scale, or a binary, coded aperture, to achieve the same objectives. In this way, we only need to insert such a pattern layer in a known camera system and such a pattern layer should be easier to fabricate. Moreover, such coded apertures usually have no chromatic aberration.

3 related work

End-to-end Lens Design V. Sitzmann et al., "End-to-end Optimization of Optics and Image Processing for Achromatic Extended Depth of Field and Super-resolution Imaging," in ACM SIGGRAPH, 2018. doi: 10.1145/3197517.3201333. In optical image recording perspective, this work is using optimized refractive optical element to change the phase of the obtained image, and this optical design eventually achieves both depth and chromatic invariance. In image processing pipeline perspective, this paper is using the Wiener deconvolution to reconstruct and deblur the image.

Transmission optics optimization H. Wang et al., "Compact Incoherent Image Differentiation with Nanophotonic Structures" in ACS Photonics Article ASAP DOI: 10.1021/acsphotonics.9b01465. This paper shows the transmission layer can perform noise-free edge detection by subtracting the optical transfer function of the structure at two different frequencies.

ADMM image processing algorithm Stephen Boyd et. al., "Distributed Optimization and Statistical Learning via the Alternating Direction Method of Multipliers"

4 Overview of the project

We combine the transmission layer design and image processing algorithm to extend the depth of field, which is to minimize the deviation between the true and the reconstructed image, over a large set of images and at different depth. We would compare our method with the lens system without a coded aperture, as well as with other coded apertures such as MURA, to evaluate the performance of such end-to-end optimization. The final goal is to show that the end-to-end optimized coded aperture, along with the post-processing, provides better all-in-focus image.

5 Milestones, timeline and intermediate goals

- Image dataset
- Simulation framework: Generate the image on sensor, for a given coded aperture and lens system
- Image processing: Reconstruct the image with the prior knowledge of the coded aperture and lens system
- Benchmark: Reproduce extended depth of field imaging with existing coded apertures.
- Optimization: Optimize the coded aperture using stochastic gradient descent.