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

Related Work
- End-to-end Lens Design: [1] used optimized refractive optical element to change the phase of the obtained image, and eventually achieves both depth and chromatic invariance, followed by an image processing pipeline.

New Technique
- Point-spread function: 
  \[ p_{\delta}(x, y) = \frac{1}{\sqrt{2\pi \sigma^2}} e^{-\frac{x^2+y^2}{2\sigma^2}} \]
- Average PSF: 
  \[ P_{\text{avg}} = \frac{1}{N} \sum_{i=1}^{N} p_{\delta_i}(x, y) \]
- Reconstruction loss: 
  \[ L = \frac{1}{N} \sum_{i=1}^{N} \| f_{\delta_i} - f_{\text{opt}} \| \]
- Optimization: gradient descent to minimize loss
  \[ \frac{k \beta_{\delta_i}}{\sigma_{\text{opt}}} = \phi_0 + 2\pi n \]

Experimental Results
- PSNR comparison for the full aperture, diffraction coded aperture and the end-to-end optimized aperture.

Conclusions
- The coded aperture is capable of extend the depth of field.
- The coded aperture designed based on diffraction optics successfully creates the second focal plane.
- With end-to-end optimization, we obtain the optimized aperture together with the parameter \( \gamma \) in the Wiener filter.

References

Fig. 1 End-to-end optimization schematic of Extended Depth of Field (EDOF)

Fig. 2 Image processing result. From left to right \( \delta = 0, 0.1, 0.2, \ldots, 0.9, 1 \)

Fig. 3 PSF comparison.

Fig. 4 PSNR comparison for the full aperture, diffraction coded aperture and the end-to-end optimized aperture.

Fig. 5 Parameter sensitivity to deconvolution parameter \( \gamma \).