

End-to-end optimization for a lensless imaging system

Cindy Nguyen { cindyn @ stanford.edu }
Department of Electrical Engineering, Stanford University

Abstract

Lensless imaging systems have been designed to capture photorealistic images at a fraction of the camera volume.

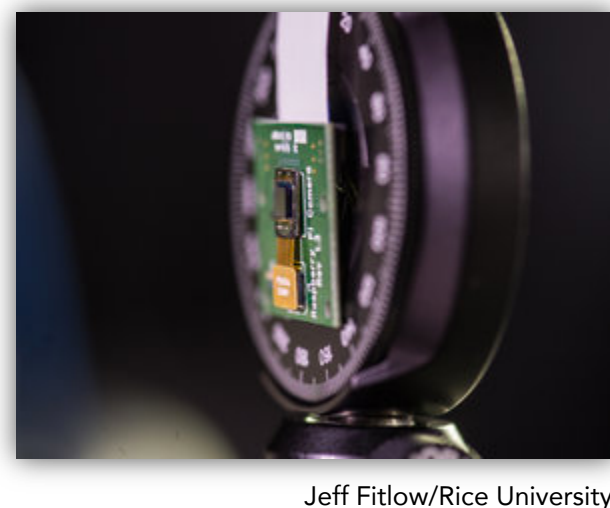
Reconstruction algorithms typically require solving a well-posed inverse problem with respect to a pre-designed phase mask.

We propose an end-to-end optimization framework that optimizes the phase mask and reconstruction algorithm jointly.

Background

Lensless Imaging

- Lensless imaging systems place a coded aperture directly in front of the sensor
- Reconstruction algorithms demultiplex the signal typically as a Tikhonov regularized least squares problem, with some deep learning^{1,2}
- Coded aperture designed first, reconstruction optimized after



Jeff Fitlow/Rice University

Deep Optics

- Optimize the diffractive optical element and reconstruction algorithm jointly³
- Applied to extended depth of field and high dynamic range imaging⁴

Methods

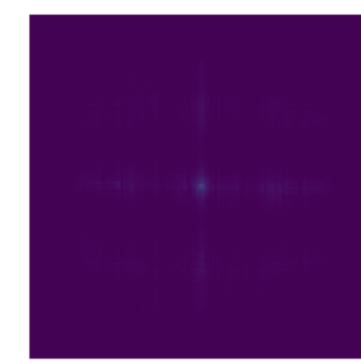
Semantic Boundaries Training Dataset



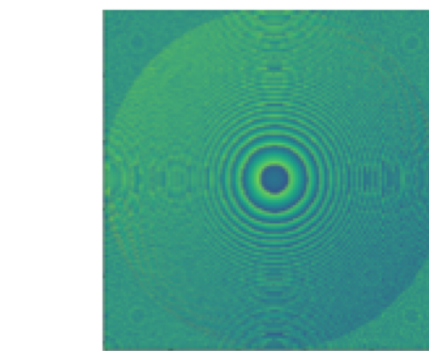
Optics Model

PSF p

*



$\frac{\partial p}{\partial h(x,y)}$



Phase Mask Height Map $h(x,y)$

- 512 x 512 resolution
- 2 μ m pixel pitch
- Wiener deconvolution given by

$$\tilde{I} = \mathcal{F}^{-1} \left\{ \frac{\tilde{p}^*}{|\tilde{p}|^2 + \gamma} \mathcal{F}\{I_\lambda\} \right\}$$

- MSE loss between ground truth and reconstructed image

Sensor Model

$\frac{\partial}{\partial p}$

$f(\cdot)$

$\frac{\partial}{\partial y}$

Reconstruction

Wiener deconvolution

$\frac{\partial \mathcal{L}}{\partial \hat{x}}$

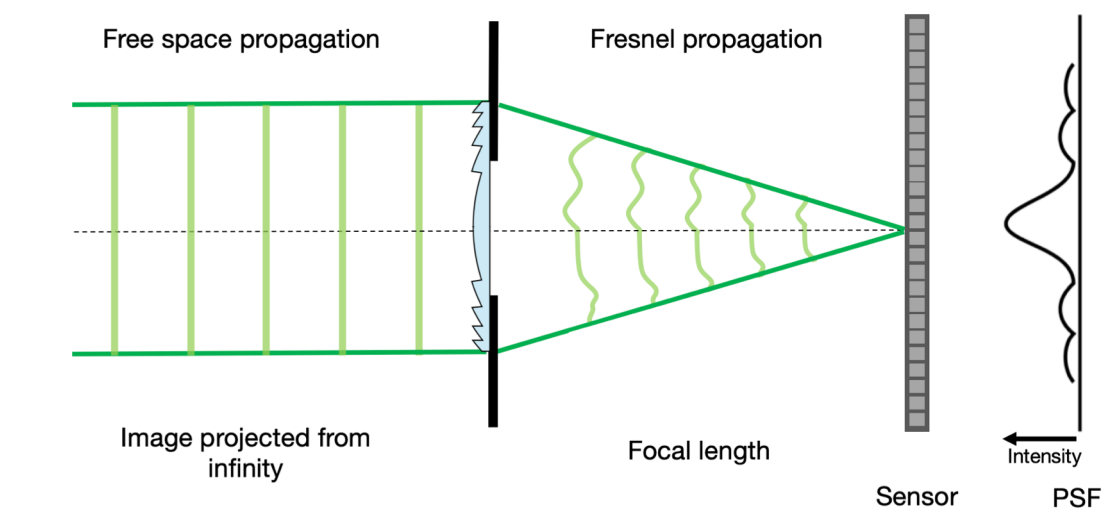
Loss

$\hat{x}$

$\mathcal{L}$

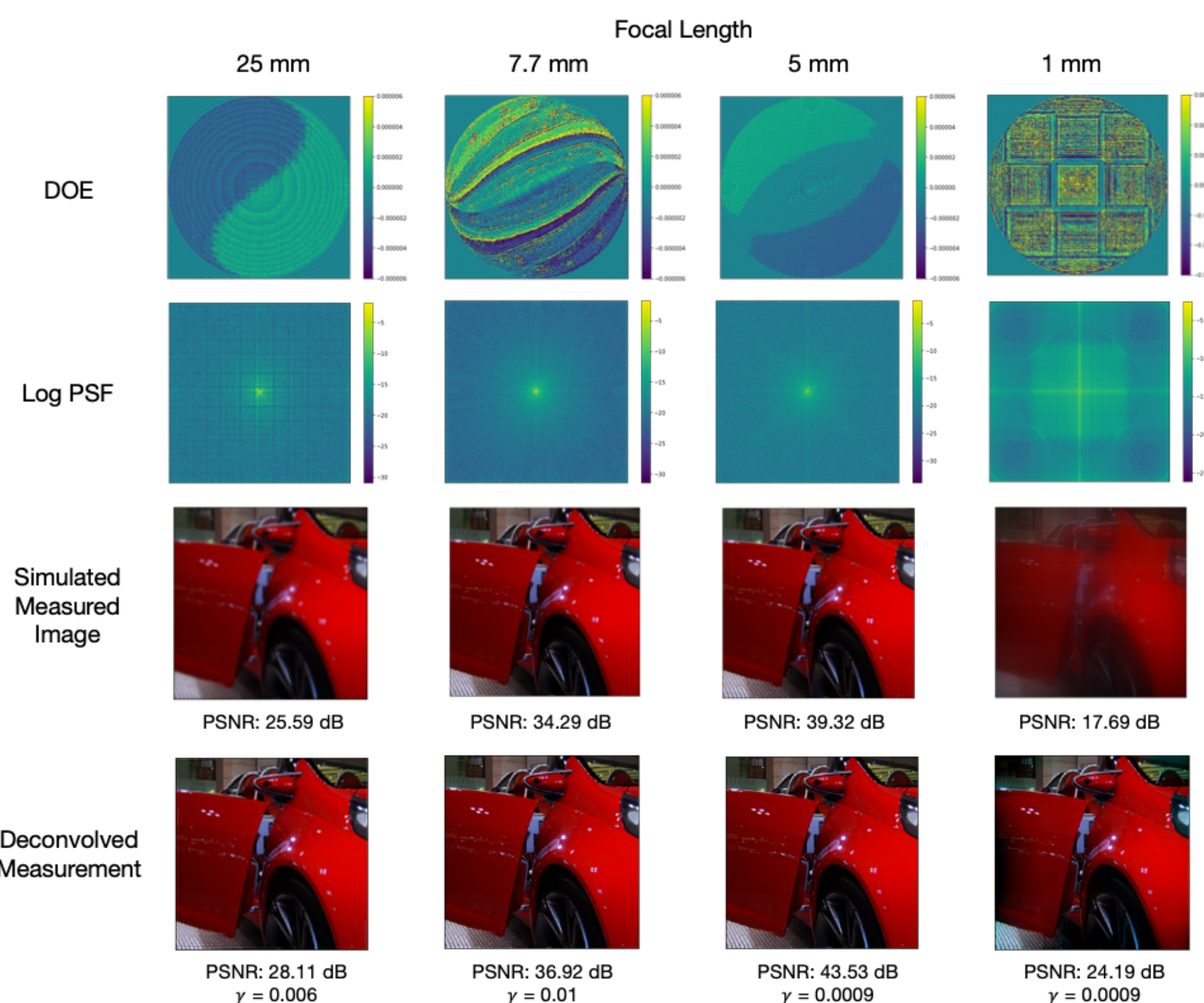
Optics Model:

point source of green wavelength modeled at optical infinity

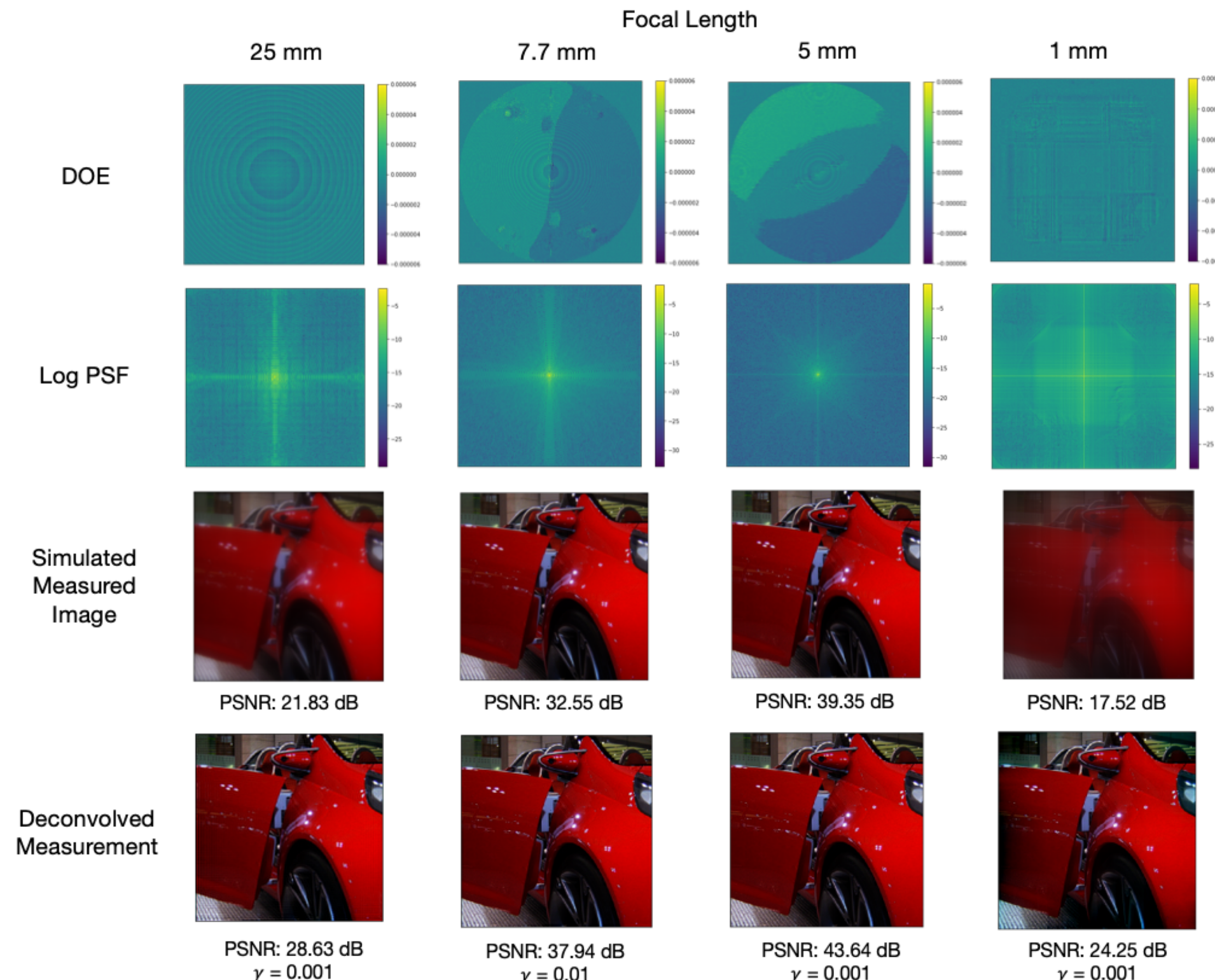


Results

Optimizing the phase mask



Optimizing the phase mask and Wiener deconvolution



Discussion

Optimizing the phase mask

- Observe opposing symmetry in learned phase masks
- Some underlying Fresnel-like structure

Optimizing the phase mask and Wiener deconvolution

- Decrease in PSNR in simulated measured image
- Increase in overall PSNR in reconstructed image

Future Directions

- Learning amplitude factor of complex-valued field
- Optimize reconstruction with U-Net
- Different loss functions and regularizers

Acknowledgements

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Source code:

github.com/ccnguyen/lensless

References

1. N. Antipa, et al. *Optica*, (1):1-9, 2018.
2. M.S. Asif, et al. *arXiv:1509.00116*, 2015.
3. V. Sitzmann, et al. *ACM Transactions on Graphics (TOG)*, 37(4):1-13, 2018
4. C.A. Metzler, et al. *arXiv:1908.00620*, 2019.