Toward Long Distance, Sub-Diffraction Imaging Using Coherent Camera Arrays

Jason Holloway†, M Salman Asif†, Manoj Kumar Sharma‡, Nathan Matsuda‡, Roarke Horstmeyer§, Oliver Cossairt‡, Ashok Veeraraghavan†

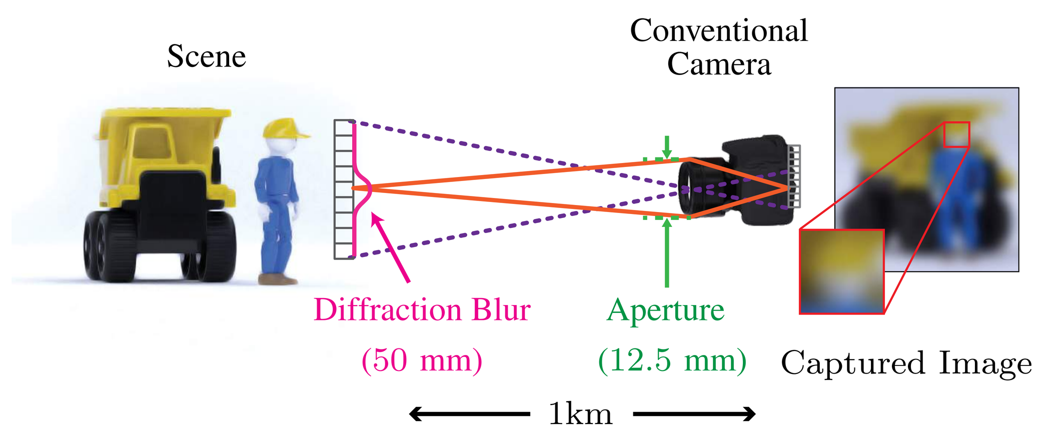
†Rice University, Houston TX ‡Northwestern University, Evanston IL §California Institute of Technology, Pasadena CA

Goal: Improve Spatial Resolution

Improve spatial resolution beyond the diffraction limit in long-distance imaging

Solution presented here: use coherent light (active illumination) to synthetically increase aperture size

Limiting Factor in Spatial Resolution

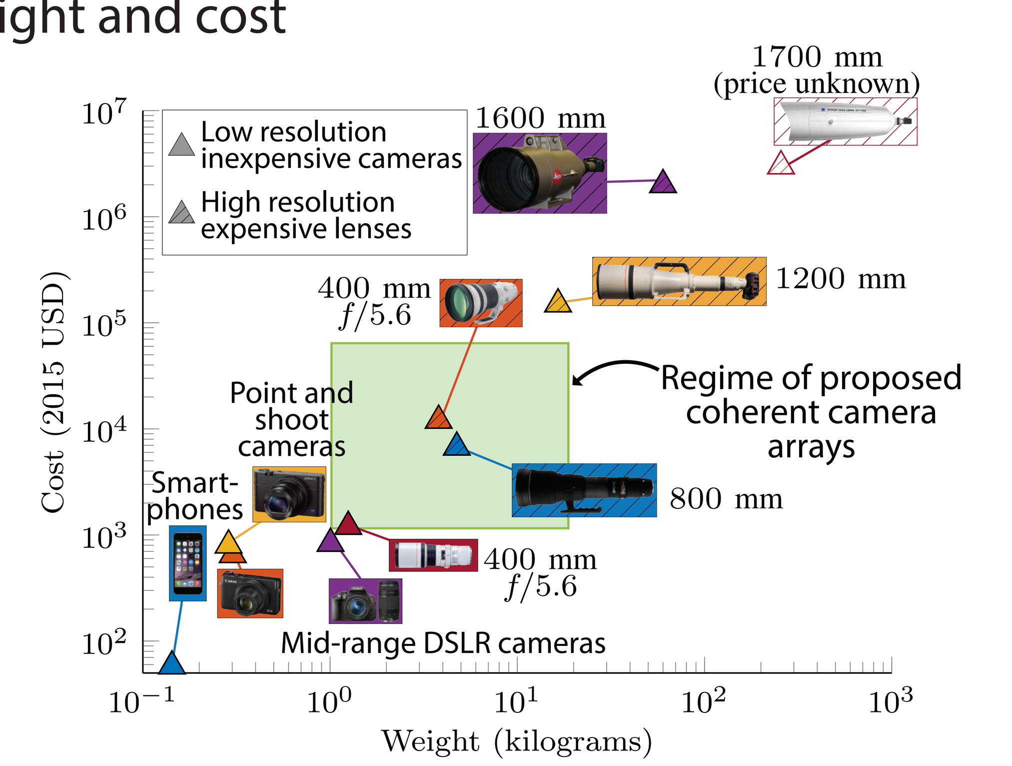


In long-distance imaging, diffraction blur limits the maximum spatial resolution that can be achieved

$$r = 1.22\frac{\lambda Z}{D}$$

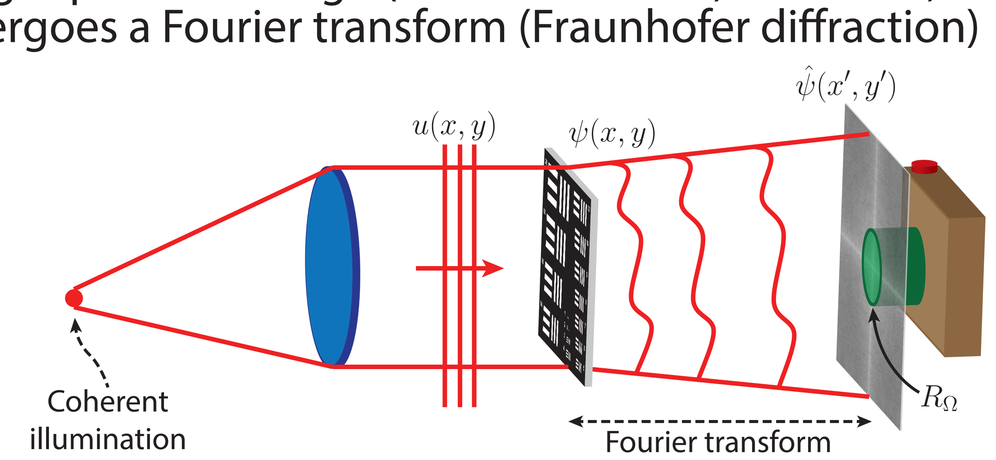
wavelength of light (λ); distance to object (Z); smallest resolveable feature on object (r); diameter of aperture (lens) (D)

Increasing diameter of the lens *drastically* increases weight and cost



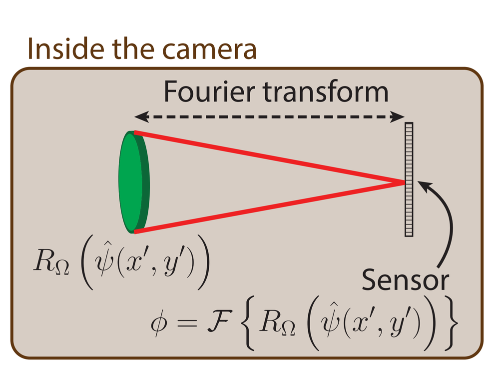
Coherent Image Formation Model

Light passes through (or reflects off of) the scene, and undergoes a Fourier transform (Fraunhofer diffraction)



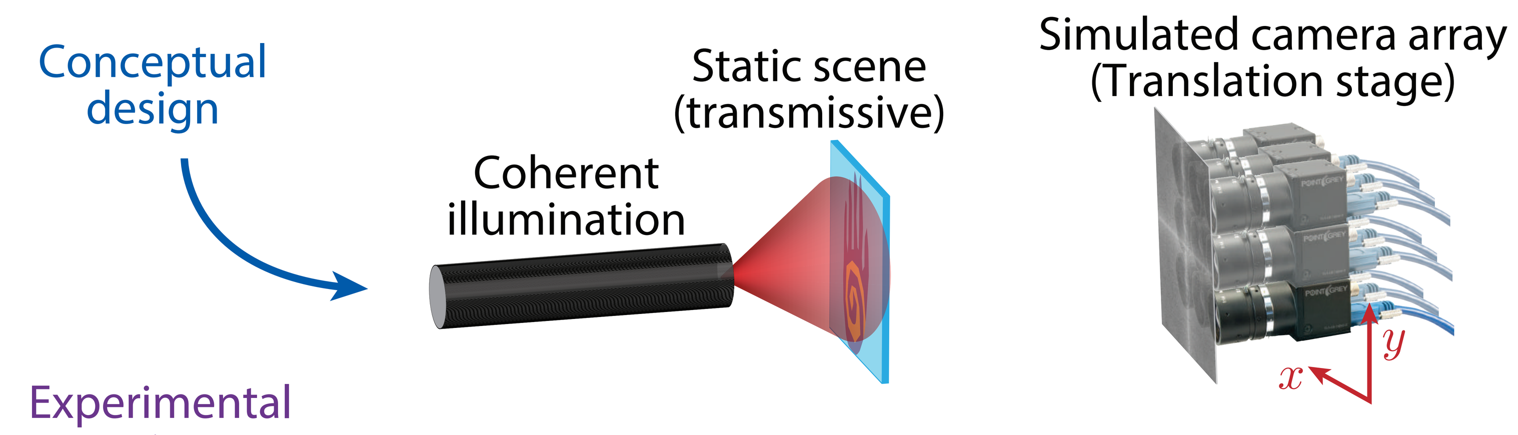
The camera lens acts as a band-pass filter and causes the light to undergo a second a Fourier transform onto the sensor plane

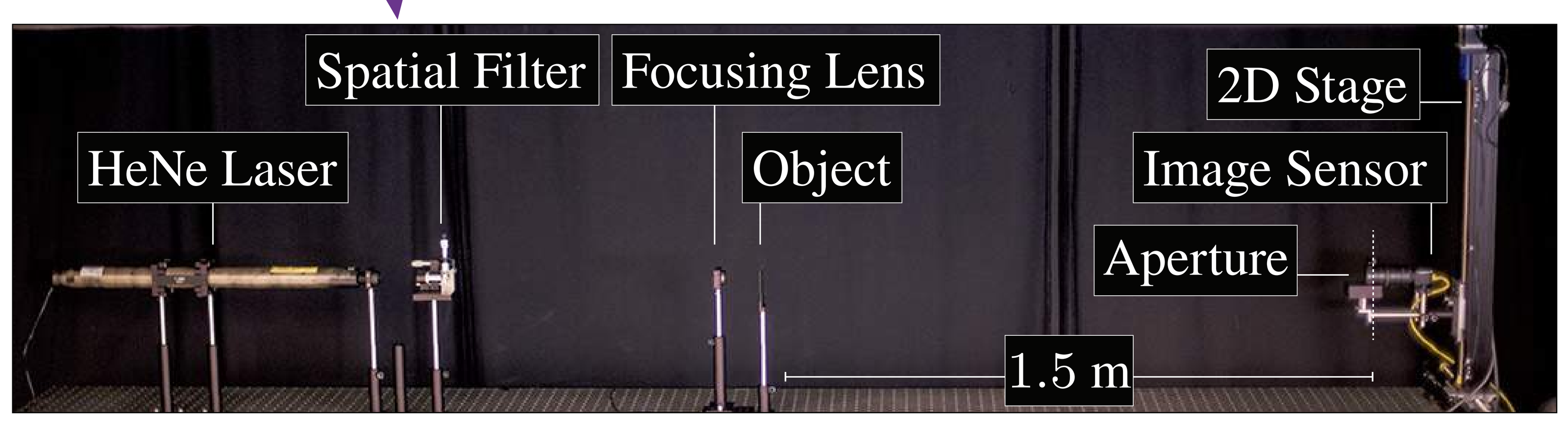
The sensor records the squared magnitude of the resulting field



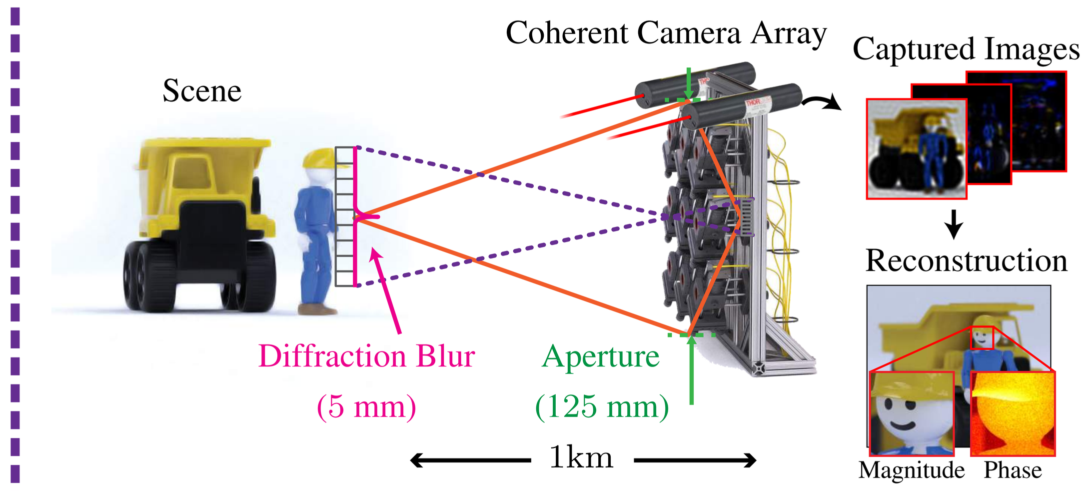
Fourier Ptychography to Improve Spatial Resolution

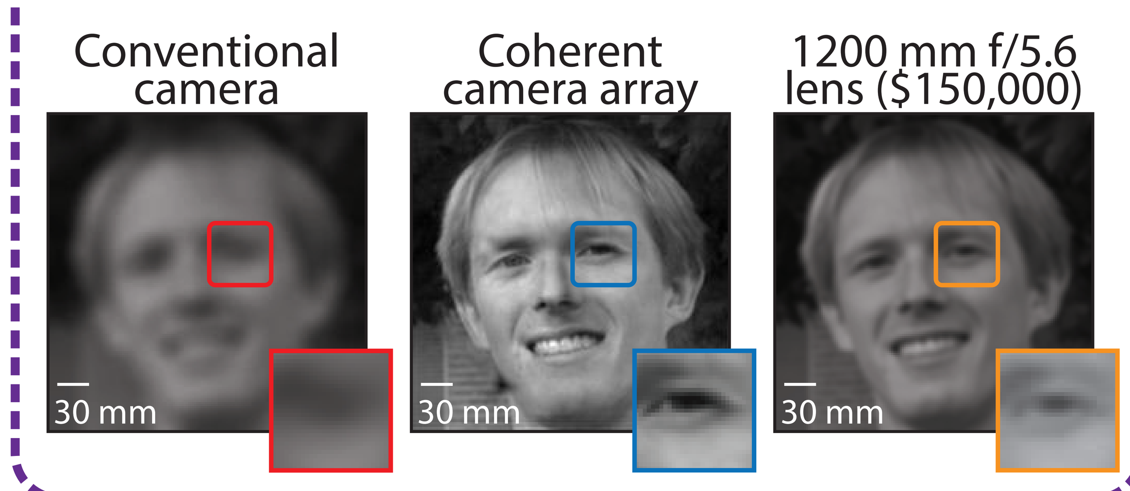
Experimental Results



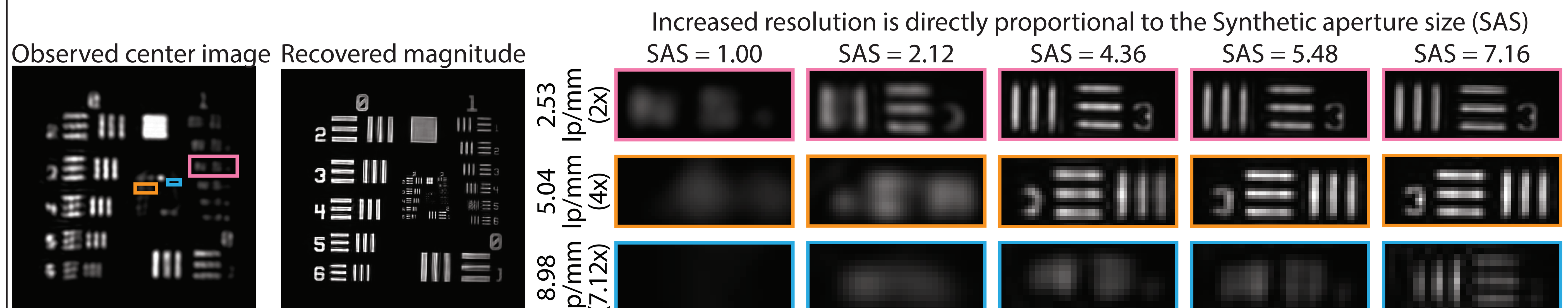


Simulation Results

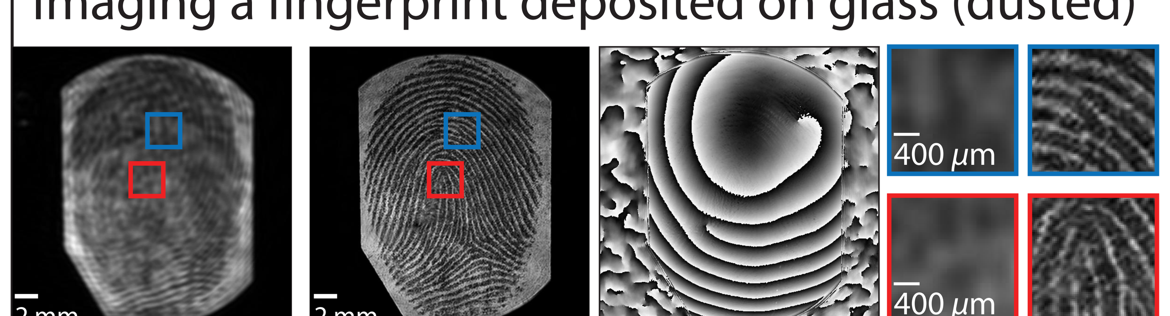




Verifying resolution gains experimentally with a resolution target 1.5 meters away

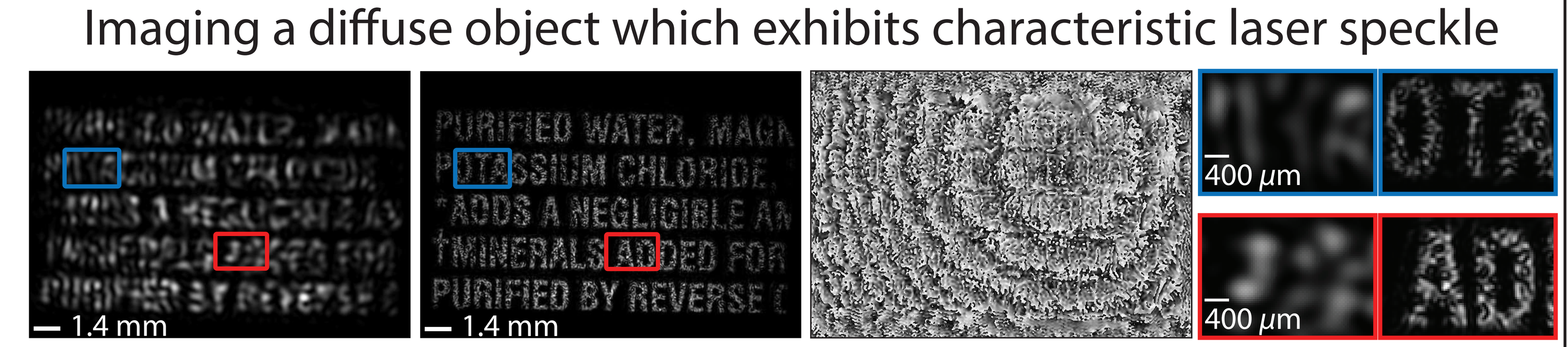


Imaging a fingerprint deposited on glass (dusted)



Observed center image | Recovered magnitude and phase | Detailed subsets

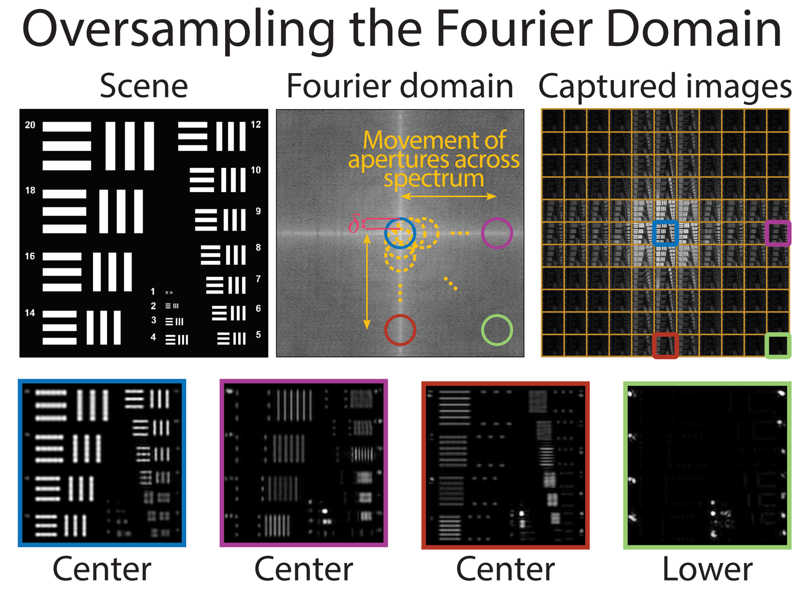
Imaging a diffuse object which exhibits characteristic laser speckle



Observed center image | Recovered magnitude and phase | Detailed subsets

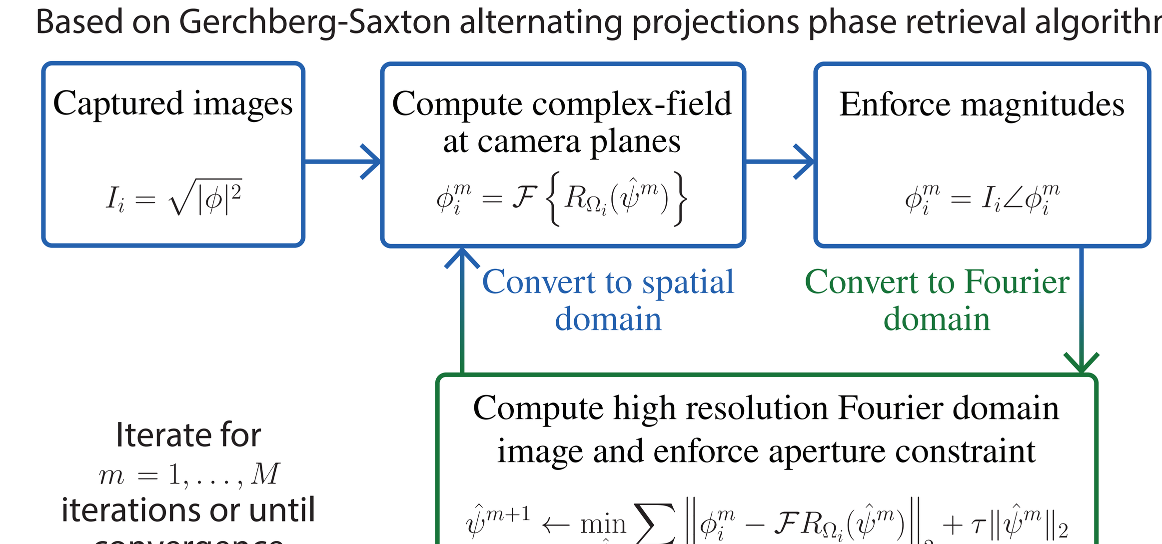
Phase Retrieval and Fourier Ptychography

Oversampling the Fourier Domain

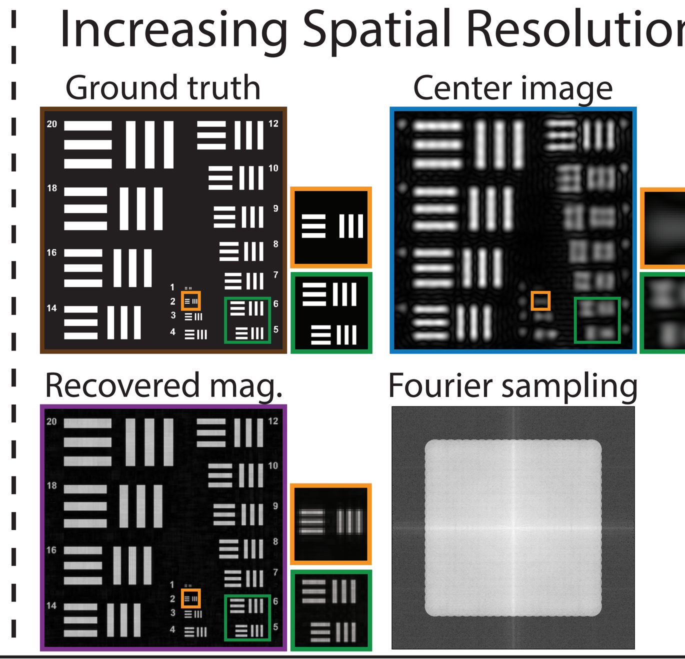


Computationally Recovering Phase Information

Based on Gerchberg-Saxton alternating projections phase retrieval algorithm



Increasing Spatial Resolution



Results

Built experimental prototype for transmissive Fourier ptychography

Demonstrated 7x increase in spatial resolution

1.5 meter separation between scene and camera platform

Successfully recovered high-resolution magnitude and phase for diffuse water bottle label

Limitations of Fourier Ptychography

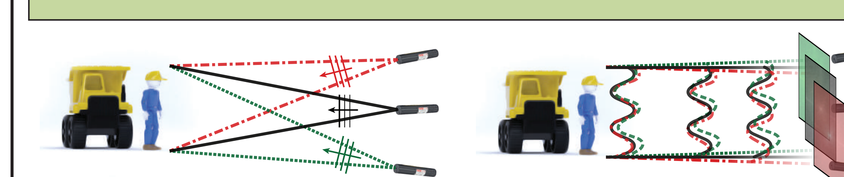
Long sampling times (>60 minutes)

Large dynamic range, 50-100x difference in brightness

Must register images with sub-pixel accuracy

Precise shifting of the camera requires motorized translation stage

Future Work



Build a camera array for simultaneous image acquisition

Use multiplexed illumination to oversample Fourier domain

Enable hand-held acquisition

Extend to reflective mode prototype

For More Information

Download the paper, code, and images at the project webpage

http://jrholloway.com/projects/towardCCA

Funding and acknowledgements

The authors would like to thank Richard Baranuik and Aggelos Katsaggelos for their thoughtful discussions and comments.

This work was supported in part by:
NSF grants IIS-1116718, CCF-1117939, CCF-1527501
NSF CAREER grant IIS-1453192
ONR grant 1(GG010550)/N00014-14-1-0741
Northwestern University McCormick Catalyst grant.