Image Enhancement Using Calibrated Lens Simulations

Jointly Image Sharpening and Chromatic Aberrations Removal

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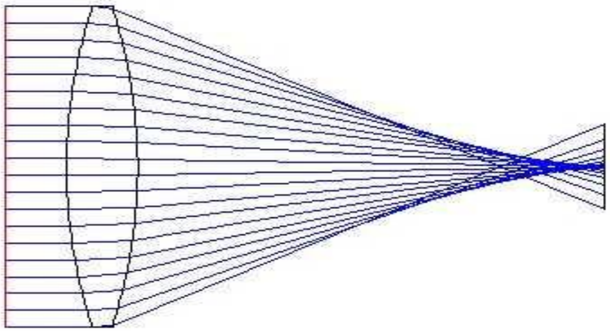
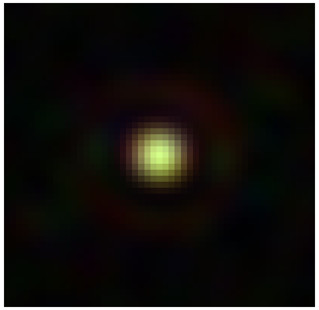
Optical Aberrations

- All lenses have optical aberrations [Seidel, 1856]
- Spherical aberration

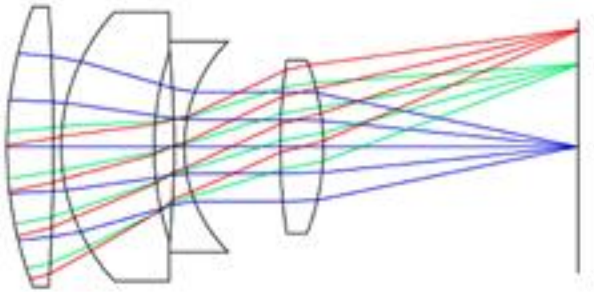


Ray Tracing



Focused PSF, but still has finite size

- Chromatic aberration (caused by dispersion of the glasses)



Ray Tracing

R/G/B are separate

Taken by Nikkon D80 + kit lens

Effect of Optical Aberrations

- Blur even the camera is focused

- Chromatic aberration and geometric distortion on the boundary

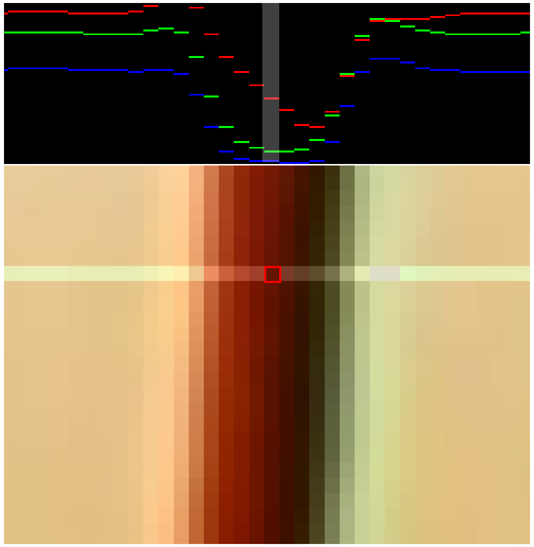
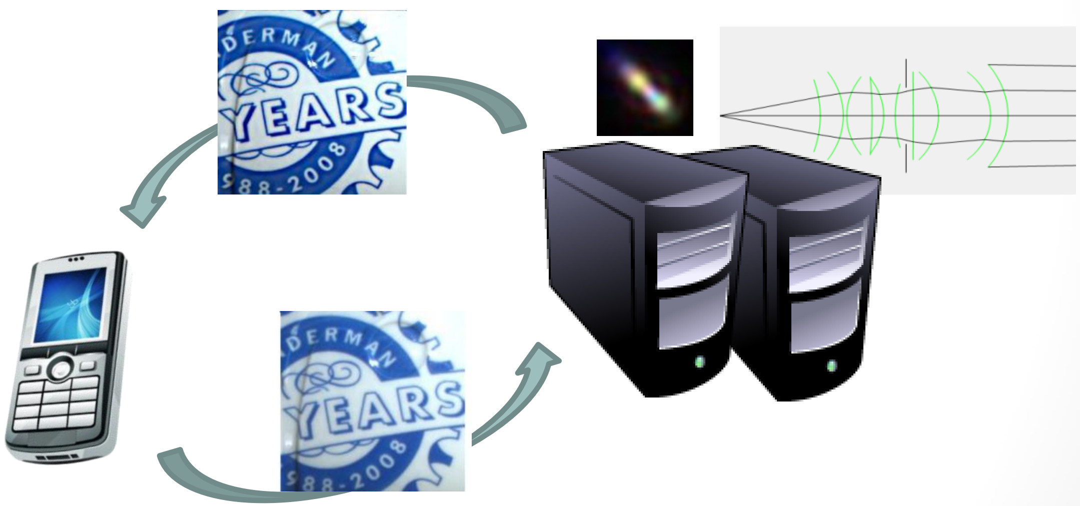


Image Enhancement

- The aberrations can be removed by deconvolution
  [B.A. Scalettar, et al 1995]
- The quality of deconvolved image depends on the PSF
- PSFs measurement is a tremendous and expensive work
  - PSFs are spatially variant
  - PSFs depends on focal plane distance
  - “Point light sources” are impossible
- Impossible to measure PSF at every position/focal plane
- Our method:
  Simulate PSFs by ray tracing using lens model

Applications

- Image enhancement by cloud computing
  - The server has an accurate lens prescription for each lens
  - The user takes an image. Uploads to the server for deconvolution
  - Remove chromatic aberrations, distortions, and sharpen the image simultaneously.



- Target applications: mobile phone cameras
  - In our work, we use small lenses. (Eg. Edmund®58202, D=9mm)
  - Most mobile phone camera lenses are prime lens. Easier to model.

Simulate PSFs by Ray Tracing

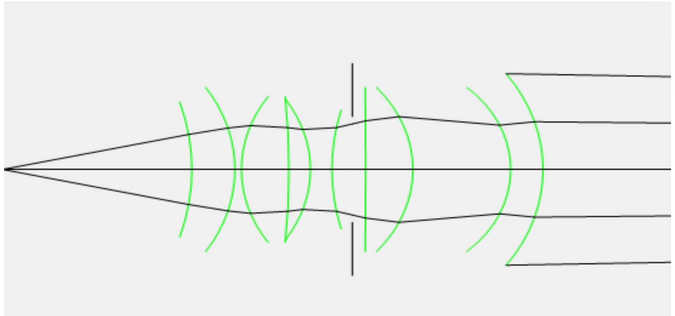
- Given a lens prescription, we trace each light ray to generate the PSFs.

- Lens prescription:

❖ Lens model

  - number of glasses

  - dispersion function of each glass



$$n^2 - 1 = C_1\lambda^2/(\lambda^2-C_2) + C_3\lambda^2/(\lambda^2-C_4) + C_5\lambda^2/(\lambda^2-C_6) \quad (n\text{:refraction index})$$

❖ Parameters

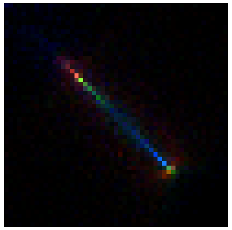
  - radius, xyz position of each glass

  - coefficients of the dispersion functions (C1…C6)

- Wave optics must be considered.

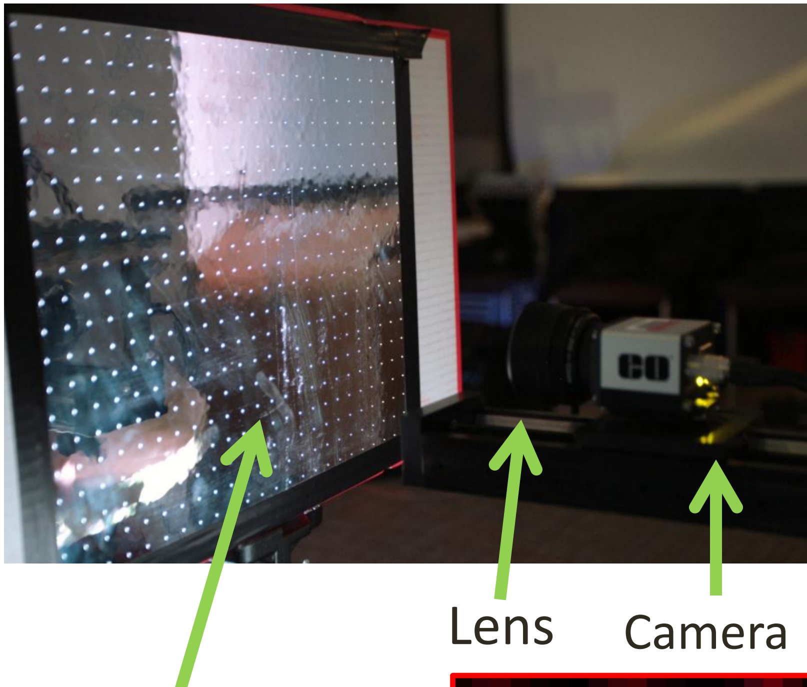
  Left: geometric ray tracing only

  Right: with Huyguens ray tracing

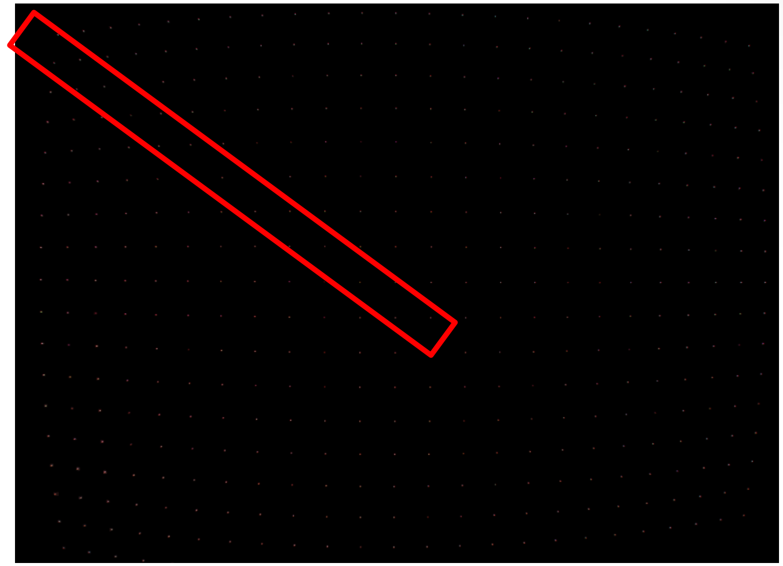


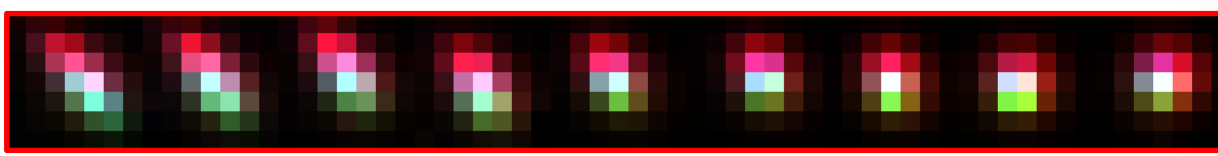
Verification by PSF Measurement

- Set up for PSFs measurement



- Measured PSFs

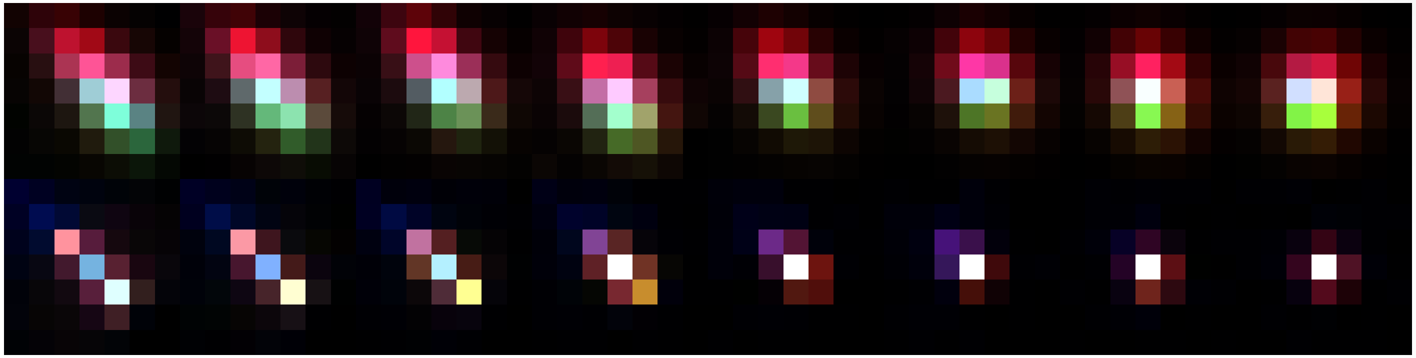




The results are unsatisfying

Measured

Synthesized by our simulator

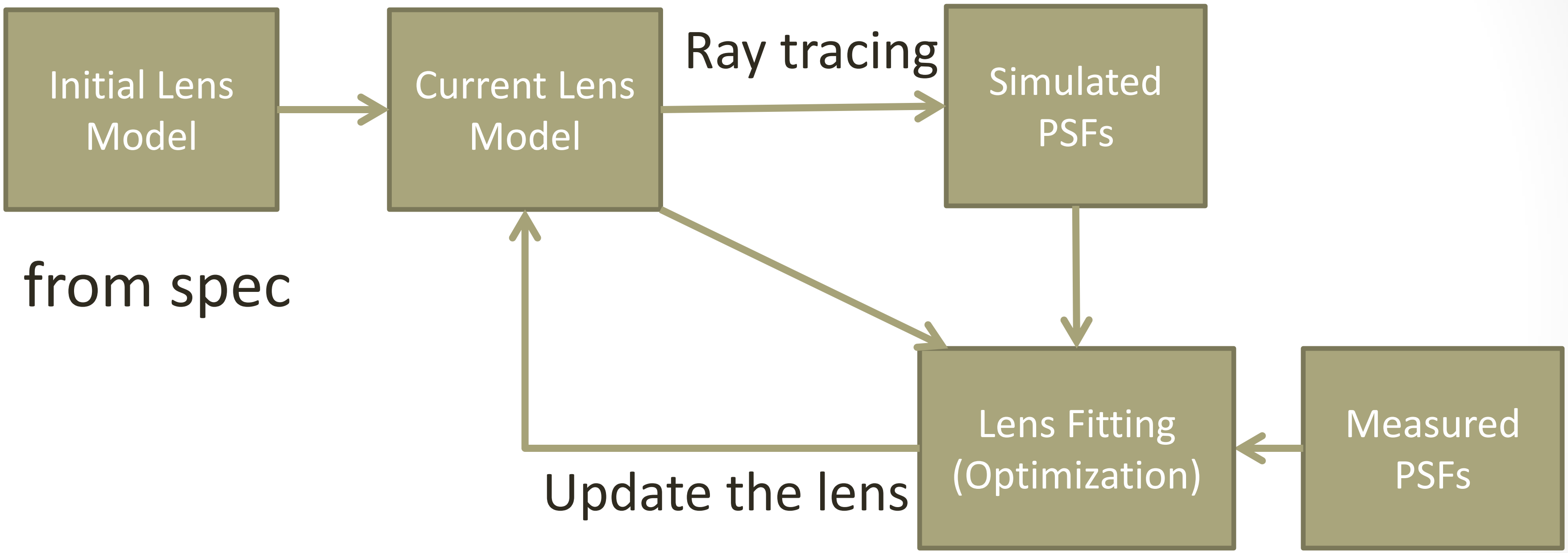


Edmund®58202

- Our assumption: model is correct, but parameters are incorrect
  - Tolerances in manufacturing
  - Small variations between lenses have a noticeable effect
- Our method:

Fit the synthetic PSFs by measured PSFs to find out the more accurate lens prescription

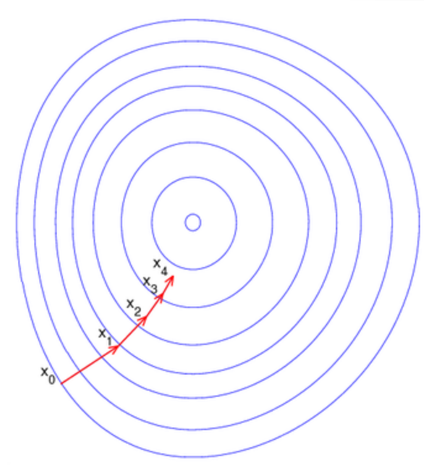
Lens Fitting



1. We measure few PSFs to fit an accurate lens model
2. Then simulate accurate PSFs for image enhancement

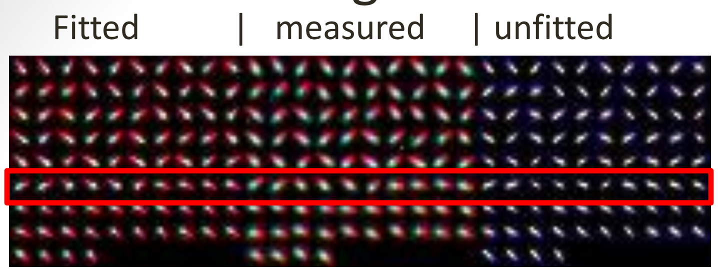
Lens Fitting (Optimization)

- Objective function: L2 norm between measured & synthetic PSFs
- Variables: lens parameters
- Optimization: gradient descent
- Initial parameters: provided lens prescription

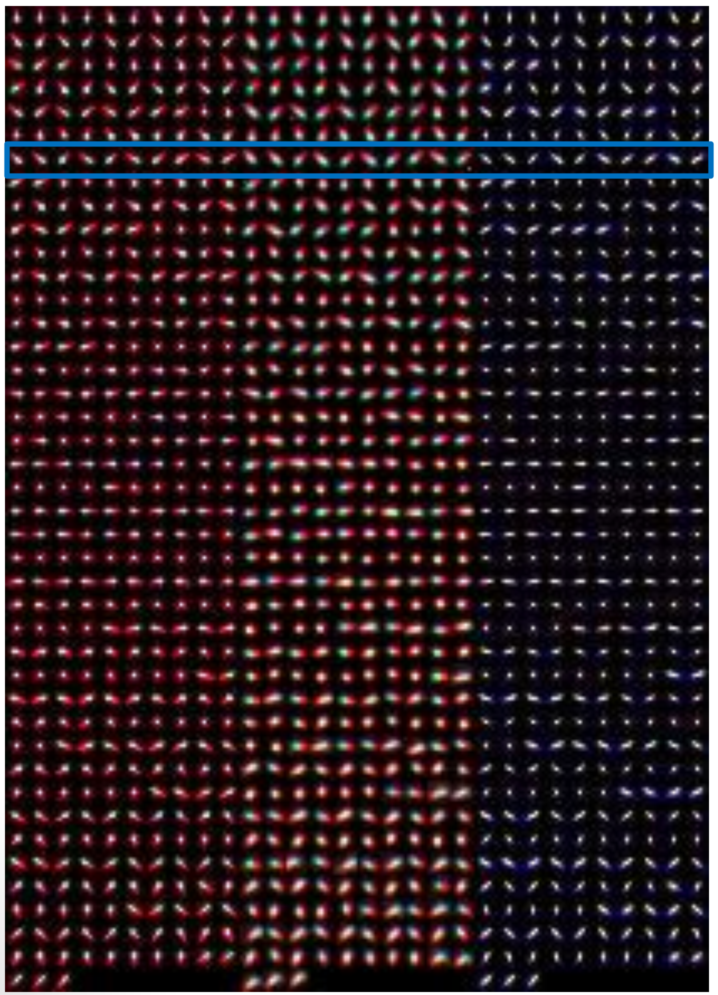


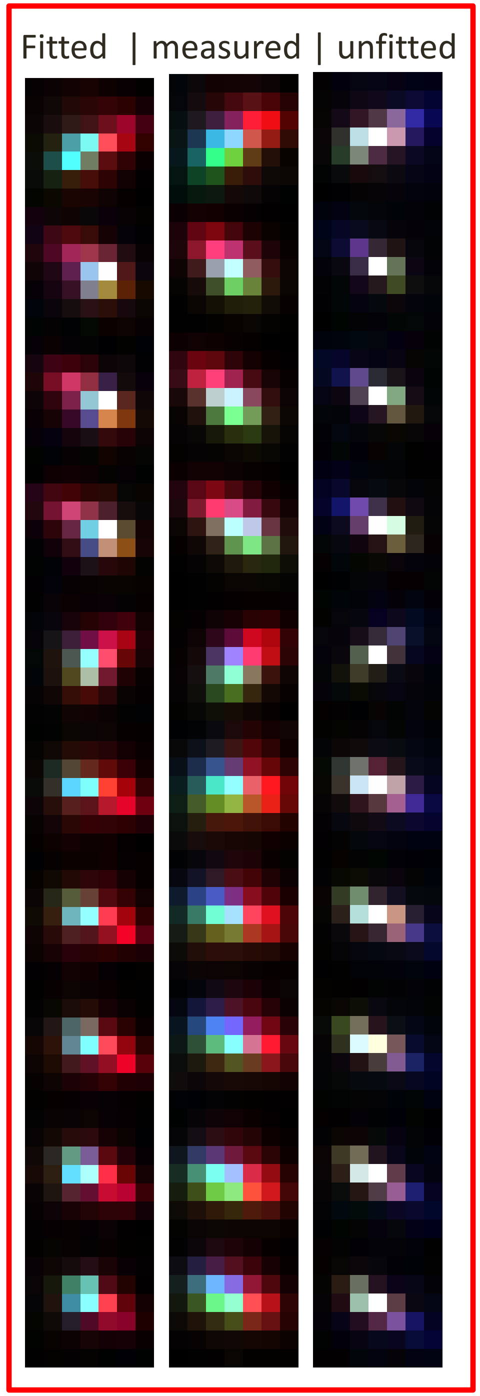
- Algorithm:
  1. Calculate the difference **D** between the measured PSFs and the synthetic PSFs by current model
  2. Calculate the gradient of each variables to find out the Jacobian **J**
  3. Move the current model by pseudoInv(**D**)***J**
  4. Go back to step 1

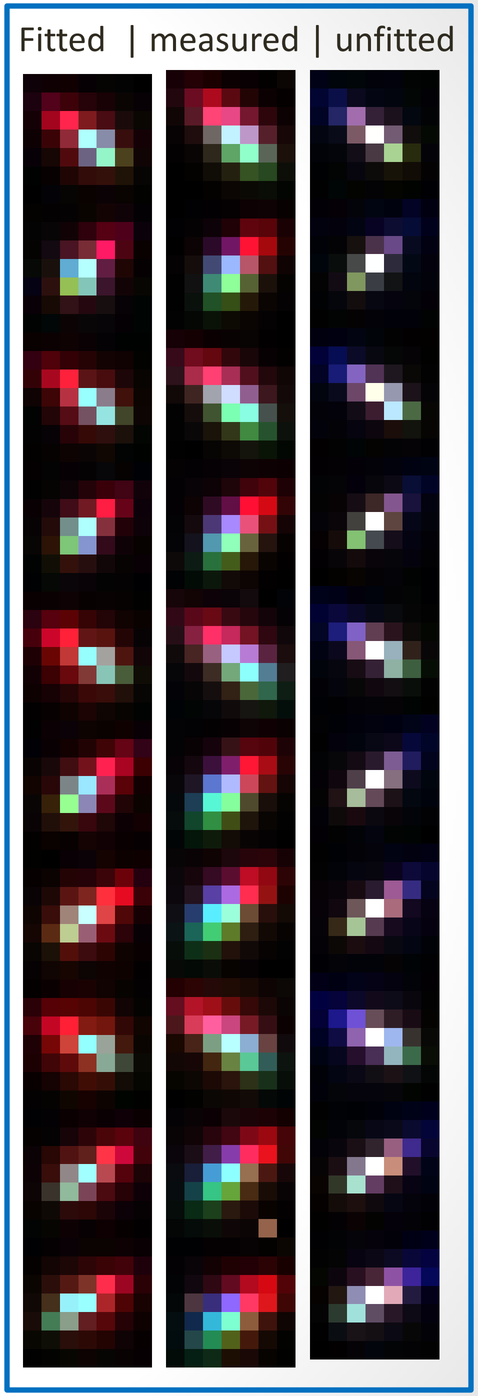
- Fitting set



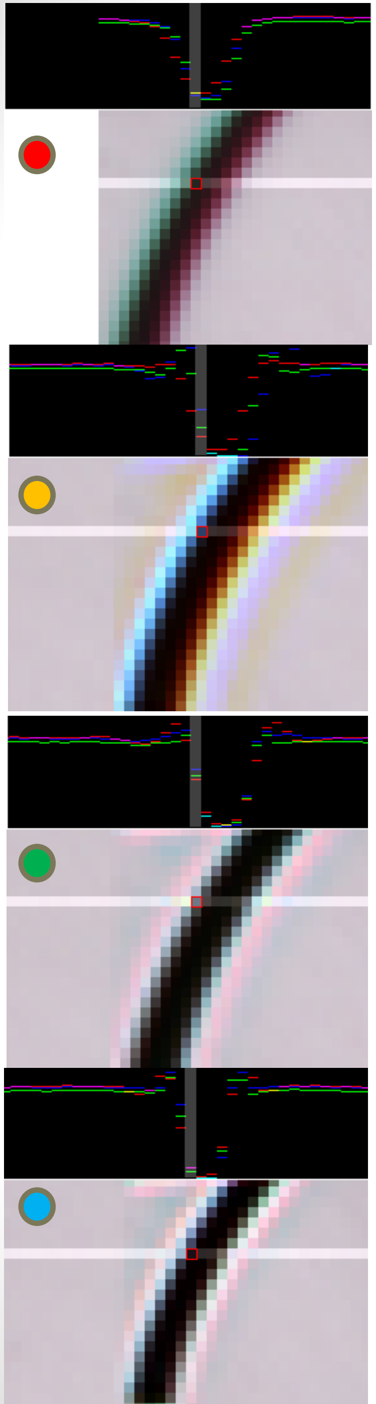
- Testing set

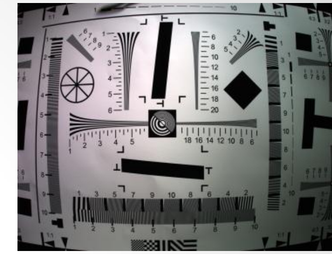






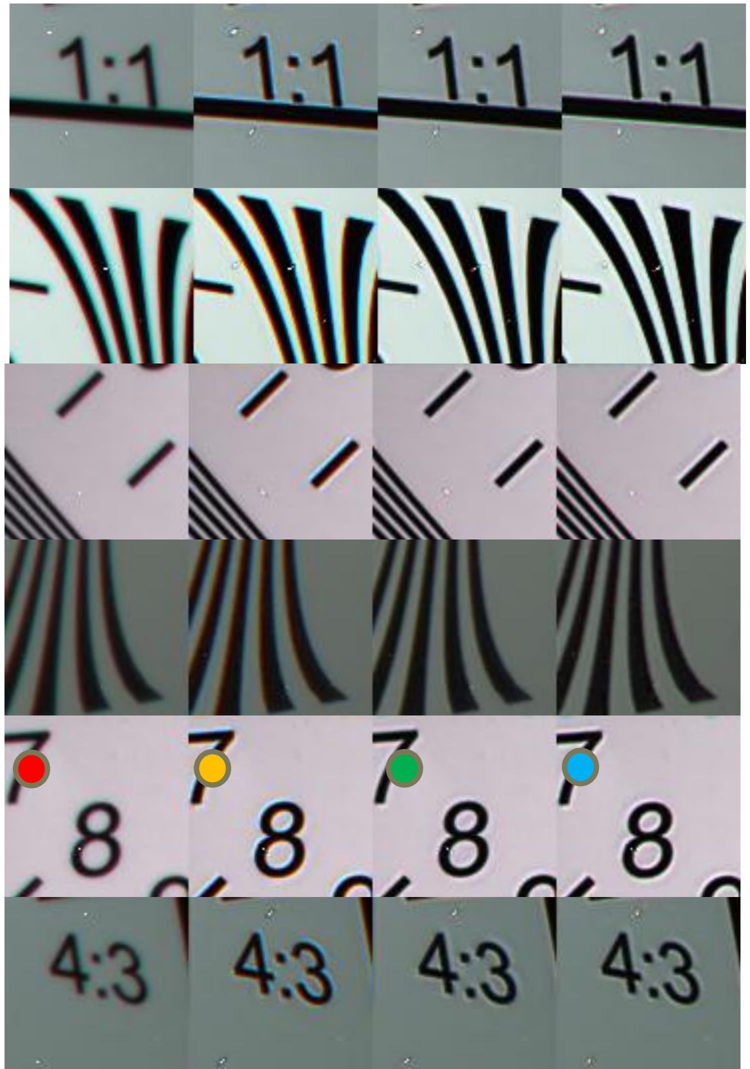
Deconvolution Results



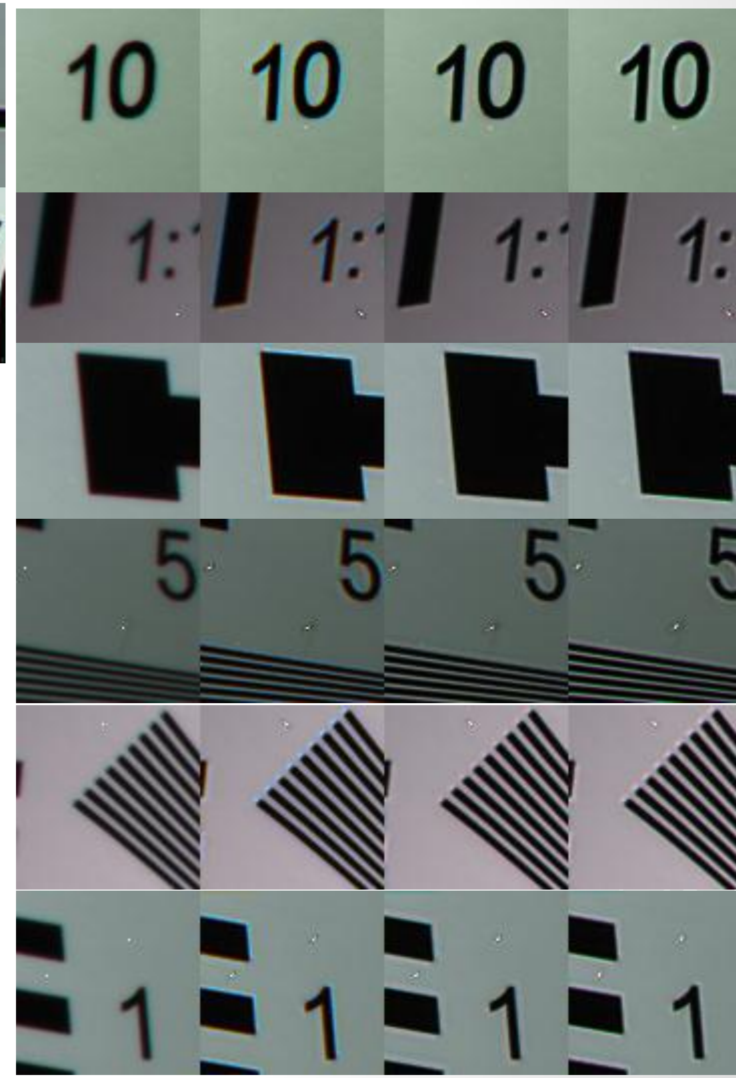


Using Lucy-Richardson method

Original | unfitted | Fitted | measured

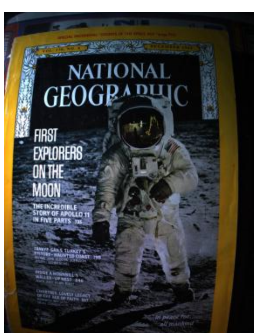


Original | unfitted | Fitted | measured



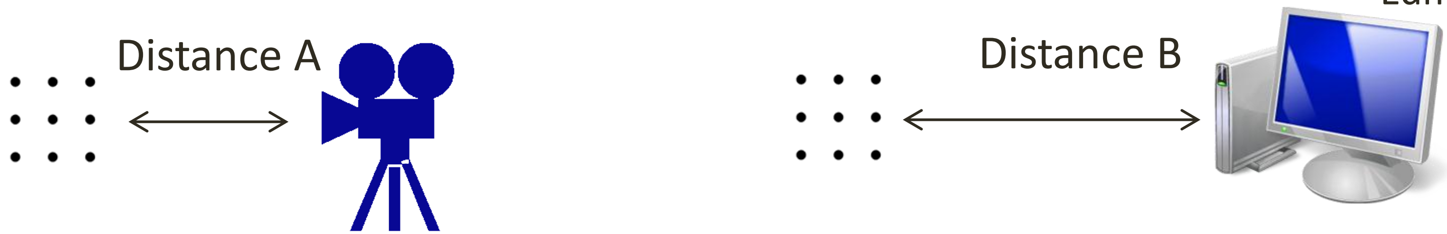
Edmund® 58202

Edmund® Double Gauss



Validation: Focus at Different Depths

Lens Model:
Edmund®58202



Fitting using measurement at distance A

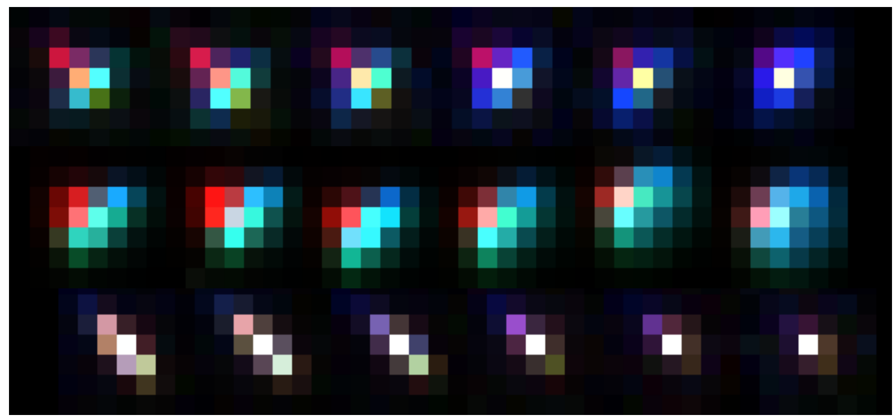
Synthesize PSFs at distance B

A = 279mm
B = 368mm

Fitted

Measured

Unfitted

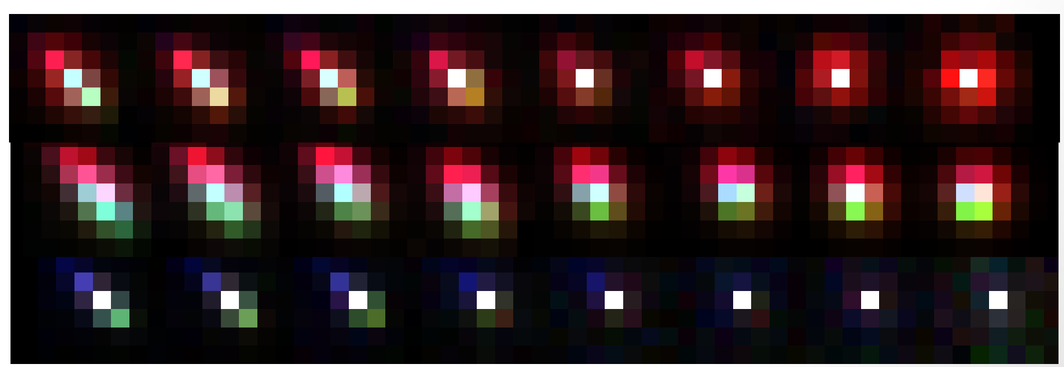


A = 368mm
B = 279mm

Fitted

Measured

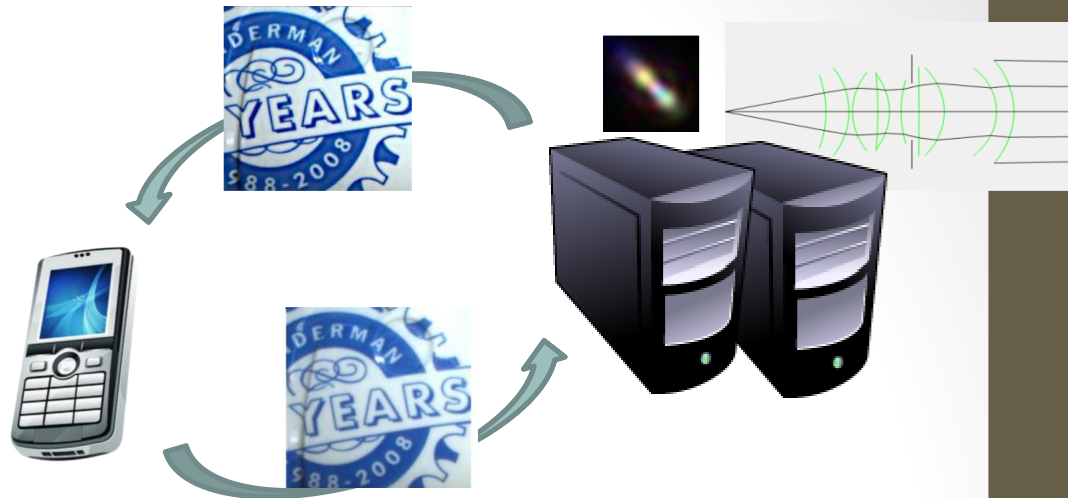
Unfitted




Original taken at 279mm
Fitted at 279mm
Fitted at 368mm
#58202
Original taken at 863mm
Fitted at 863mm
Fitted at 1282mm
#54857
Original taken at 511mm
Fitted at 842mm
Fitted at 711mm
#54854

Original taken at 279mm
Fitted at 279mm
Fitted at 368mm
#58202
Original taken at 863mm
Fitted at 863mm
Fitted at 1282mm
#54857
Original taken at 572mm
Fitted at 842mm
Fitted at 711mm
#54854

Conclusion



- Our method can predict PSFs at
  - Different spatial positions
  - Different focal planes
- But requires calibration on every lens

- Deconvolution with synthetic PSFs can sharpen the image and remove the chromatic aberrations simultaneously

- Distortion can be corrected in our framework


Original taken at 279mm
Fitted at 279mm
Fitted at 368mm
#58202
Original taken at 863mm
Fitted at 863mm
Fitted at 1282mm
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