

# MATLAB Calibration Toolbox Demo

[https://www.vision.caltech.edu/bouguetj/calib\\_doc/](https://www.vision.caltech.edu/bouguetj/calib_doc/)



Current Folder

Name
image0000001.jpg
image0000002.jpg
image0000003.jpg
image0000004.jpg
image0000005.jpg
image0000006.jpg
image0000007.jpg
image0000008.jpg
image0000009.jpg
image0000010.jpg
image0000011.jpg
image0000012.jpg
image0000013.jpg
image0000014.jpg
image0000015.jpg
image0000016.jpg
image0000017.jpg
image0000018.jpg
image0000019.jpg
image0000020.jpg
image0000021.jpg
image0000022.jpg
image0000023.jpg
image0000024.jpg
image0000025.jpg
image0000026.jpg
image0000027.jpg
image0000028.jpg

Command Window

New to MATLAB? See resources for [Getting Started](#).

```
>> cd C:\Users\hspark\Desktop\Lecture\calib\image  
>> addpath C:\Users\hspark\Desktop\Lecture\calib\toolbox_calib\TOOLBOX_calib  
>> calib
```

fx >

Run calibration

 Camera Calibration Toolbox - Select m...  
Standard (all the images are stored in memory)  
Memory efficient (the images are loaded one by one)  
Exit

Standard mode

↓

Read image

Current Folder

Name
image0000001.jpg
image0000002.jpg
image0000003.jpg
image0000004.jpg
image0000005.jpg
image0000006.jpg
image0000007.jpg
image0000008.jpg
image0000009.jpg
image0000010.jpg
image0000011.jpg
image0000012.jpg
image0000013.jpg
image0000014.jpg
image0000015.jpg
image0000016.jpg
image0000017.jpg
image0000018.jpg
image0000019.jpg
image0000020.jpg
image0000021.jpg
image0000022.jpg
image0000023.jpg
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image0000025.jpg
image0000026.jpg
image0000027.jpg
image0000028.jpg

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```
>> cd C:\Users\hspark\Desktop\Lecture\calib\image
>> addpath C:\Users\hspark\Desktop\Lecture\calib\toolbox_calib\TOOLBOX_calib
>> calib

.
..
image000001.jpg image000008.jpg image000015.jpg image000022.jpg
image000002.jpg image000009.jpg image000016.jpg image000023.jpg
image000003.jpg image000010.jpg image000017.jpg image000024.jpg
image000004.jpg image000011.jpg image000018.jpg image000025.jpg
image000005.jpg image000012.jpg image000019.jpg image000026.jpg
```

Image prefix

```
Basename camera calibration images (without number nor suffix): >> image00000
Image format: ([]='r'='ras', 'b'='bmp', 't'='tif', 'p'='pgm', 'j'='jpg', 'm'='ppm') j
```

Image extension

```
Loading image 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...20
done
fx >> |
```

Current Folder

Name

- image000001.jpg
- image000002.jpg
- image000003.jpg
- image000004.jpg
- image000005.jpg
- image000006.jpg
- image000007.jpg
- image000008.jpg
- image000009.jpg
- image000010.jpg
- image000011.jpg
- image000012.jpg
- image000013.jpg
- image000014.jpg
- image000015.jpg
- image000016.jpg
- image000017.jpg
- image000018.jpg
- image000019.jpg
- image000020.jpg
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```
>> cd C:\Users\hspark\Desktop\Lecture\calib\image
>> addpath C:\Users\hspark\Desktop\Lecture\calib\toolbox_calib\TOOLBOX_calib
>> calib
```

Camera Calibration Toolbox - Standard Version

Image names	Read images	Extract grid corners	Calibration
Show Extrinsic	Reproject on images	Analyse error	Recomp. corners
Add/Suppress images	Save	Load	Exit
Comp. Extrinsic	Undistort image	Export calib data	Show calib results

image000005.jpg image000012.jpg image000019.jpg image000026.jpg

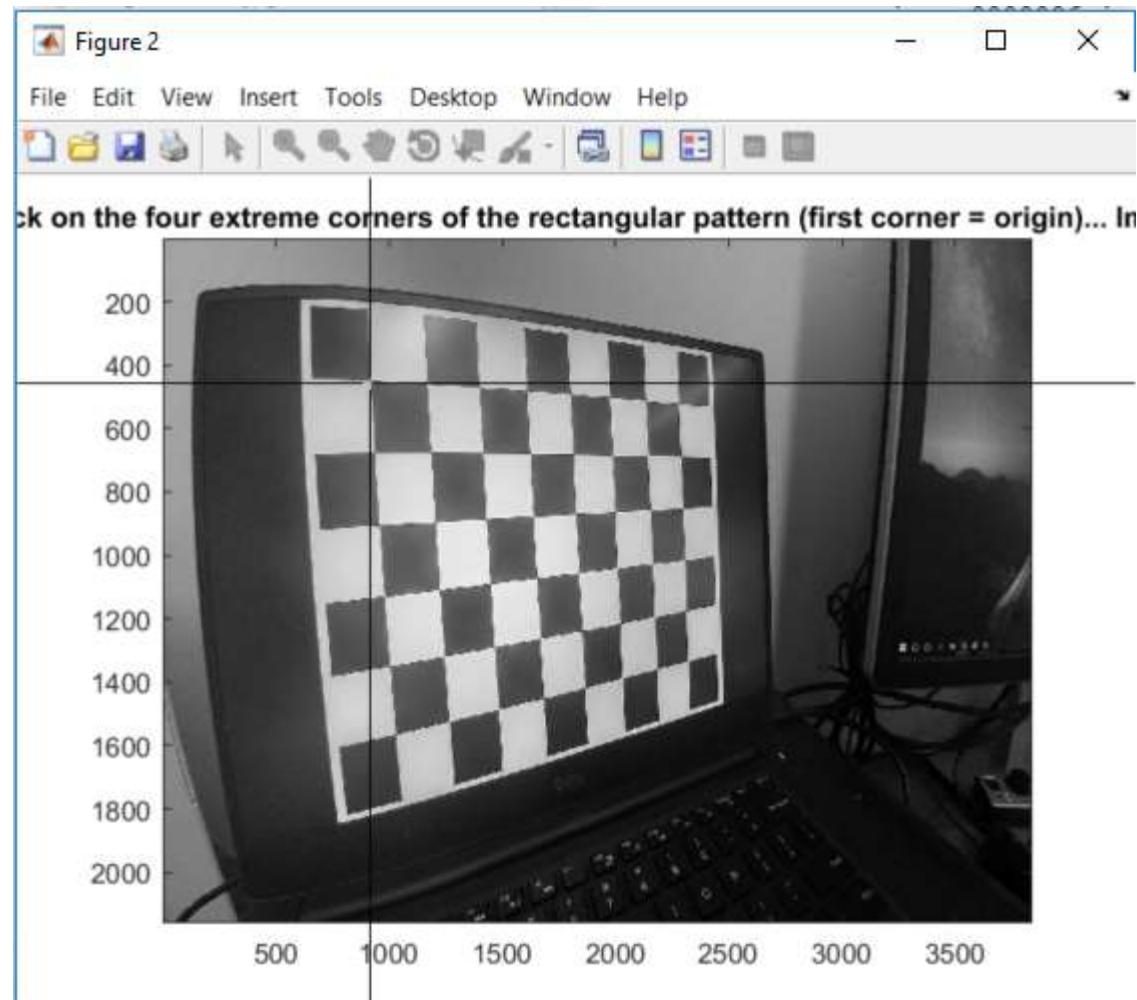
Basename camera calibration images (without number nor suffix): >> image00000

Image format: ([]='r'='ras', 'b'='bmp', 't'='tif', 'p'='pgm', 'j'='jpg', 'm'='ppm') j

Loading image 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...17...18...19...2

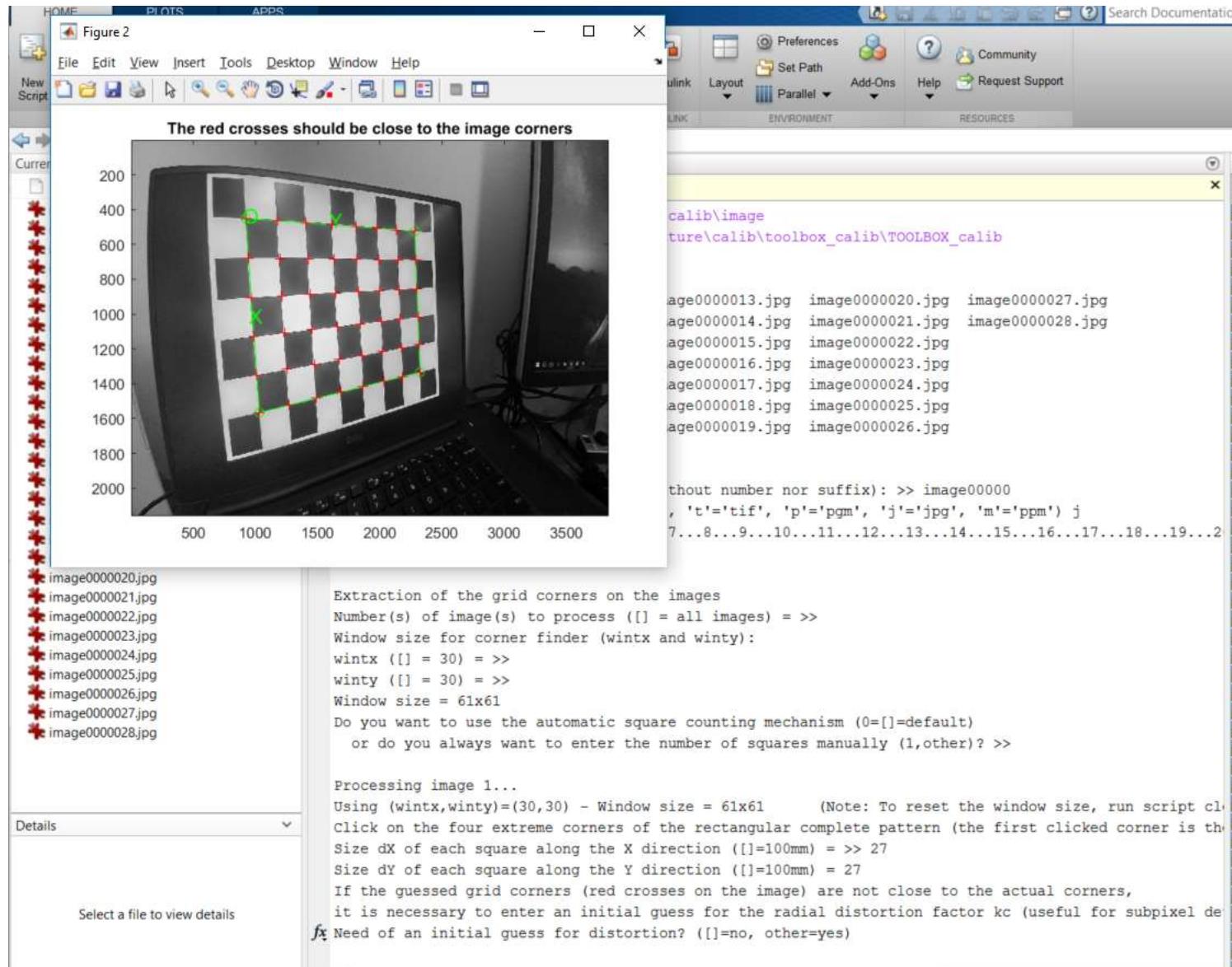
done

fx >>



Click four corner in the following order:

1. Top left
2. Top right
3. Bottom right
4. Bottom left



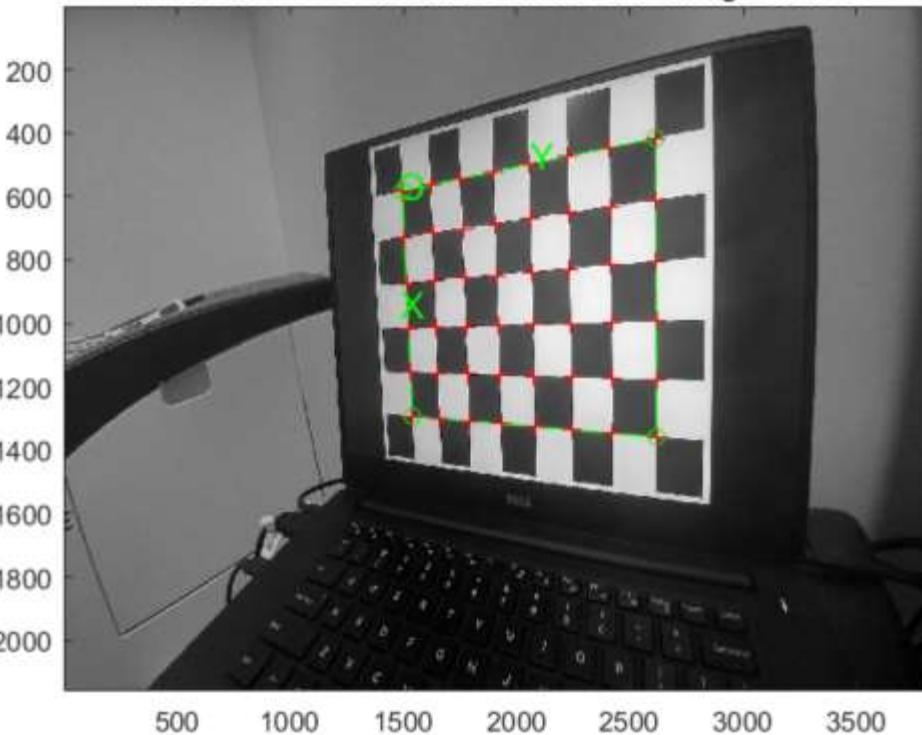
Default mode (press Enter)

Set grid size (27mm)

Figure 2

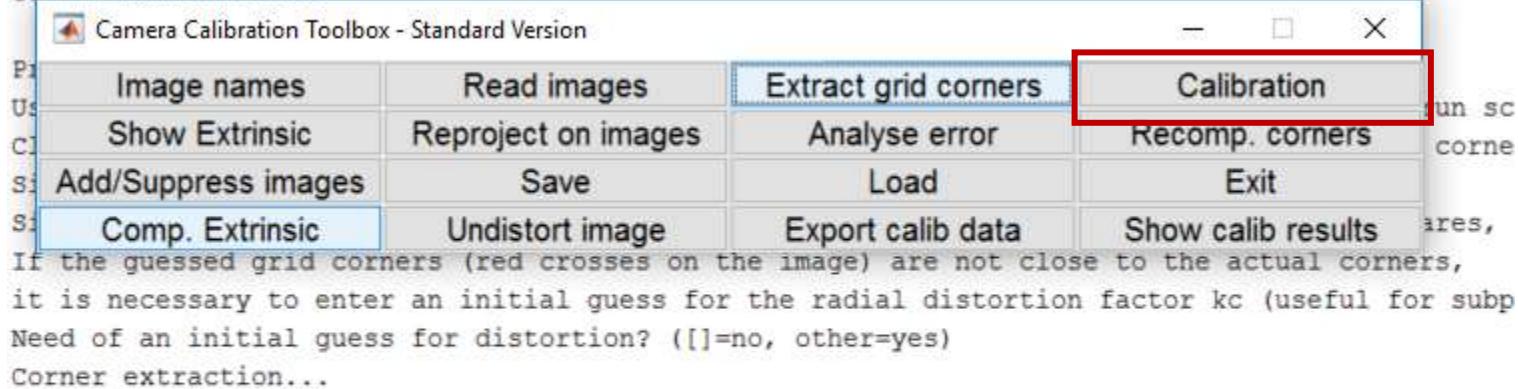


The red crosses should be close to the image corners



```
Need of an initial guess for distortion? ([]=no, other=yes)
```

```
Corner extraction...
```



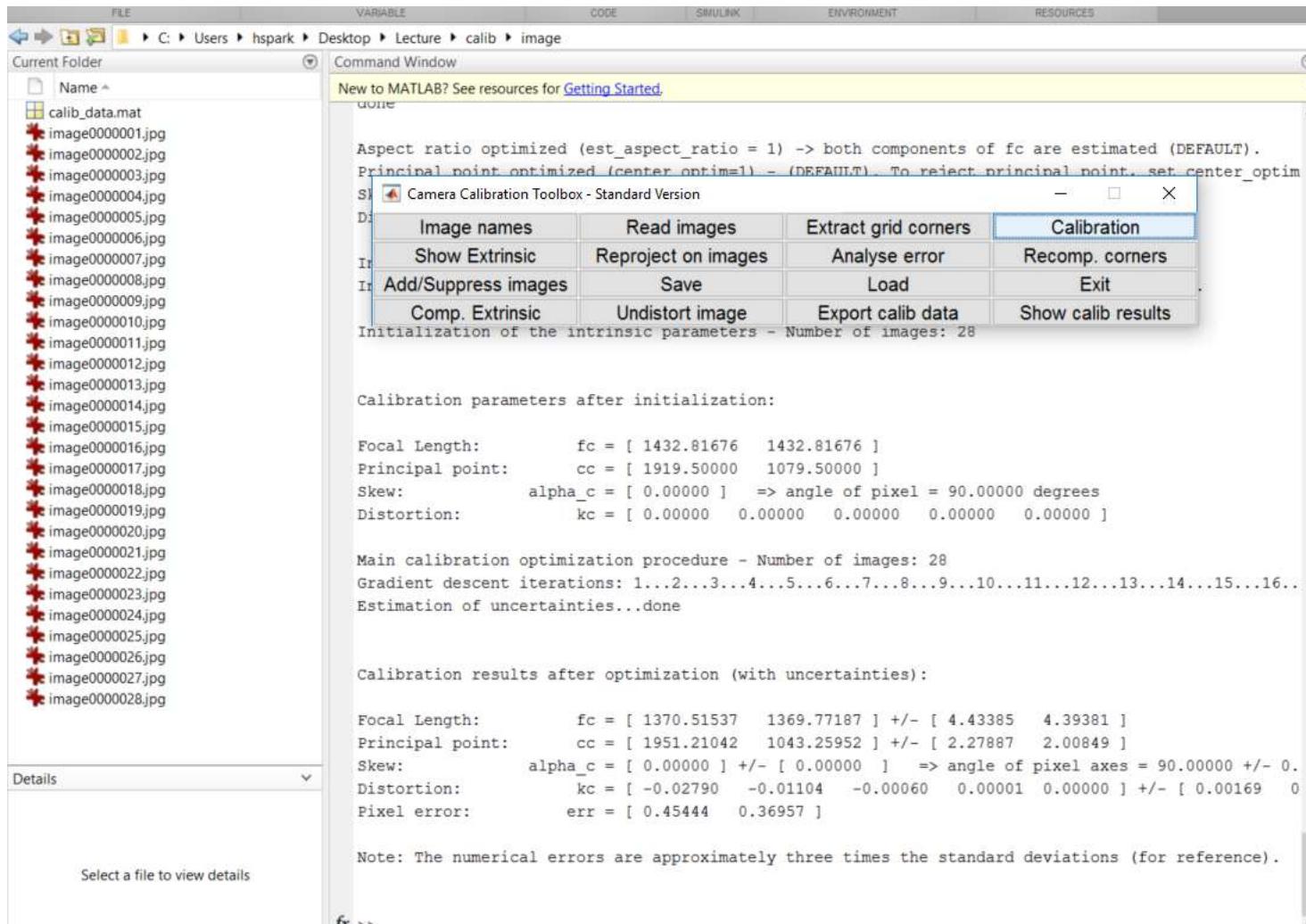
```
Processing image 27...
```

```
Using (wintx,winty)=(30,30) - Window size = 61x61 (Note: To reset the window size, run sc)
```

```
Click on the four extreme corners of the rectangular complete pattern (the first clicked corne
```

```
Size of each square along the X direction: dX=27mm
```

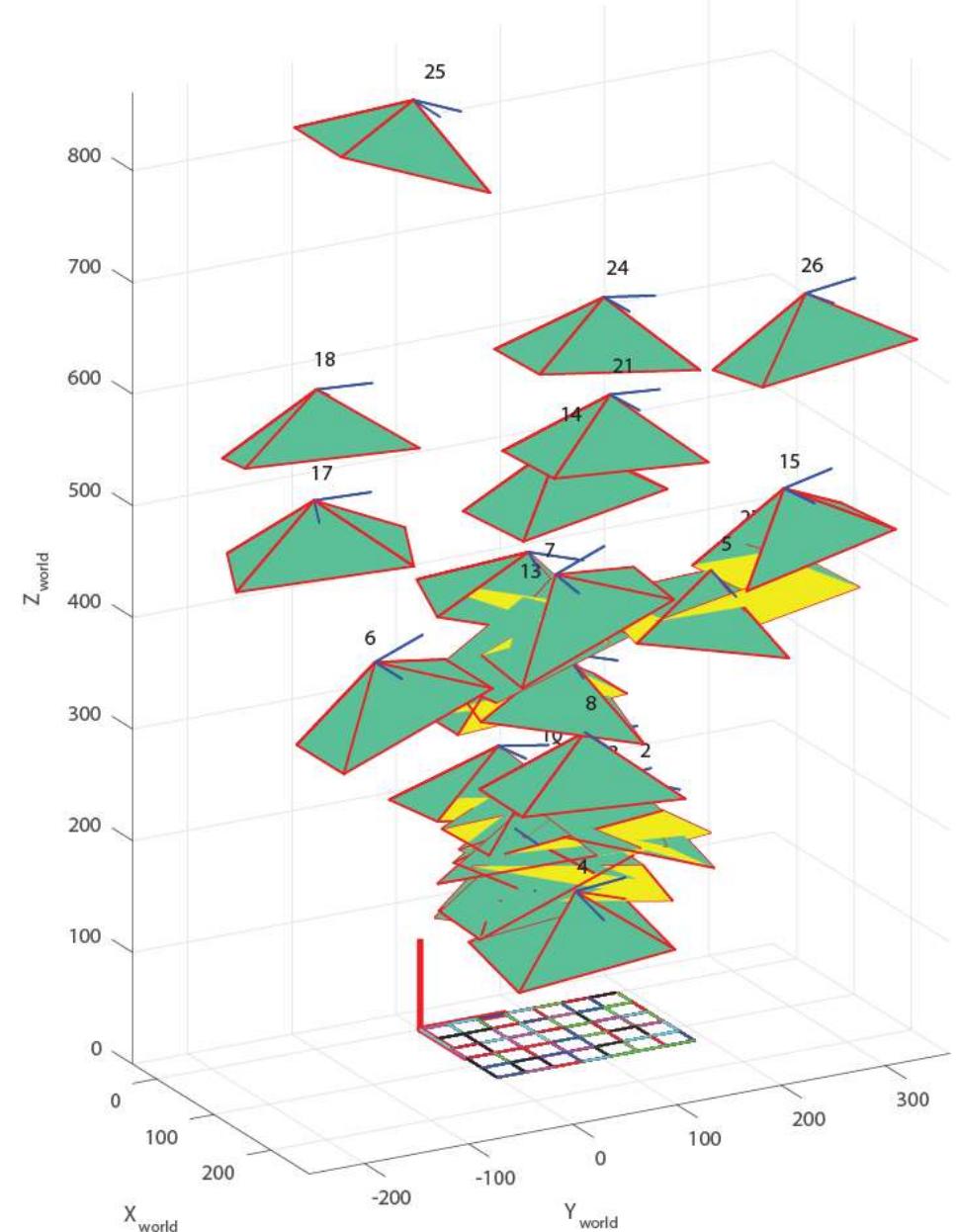
```
Size of each square along the Y direction: dY=27mm (Note: To reset the size of the squares,
```



Cf) calibration with vanishing points

$$K = \begin{bmatrix} 1317.2 & 0 & 1931.8 \\ 0 & 1317.2 & 1146.1 \\ 0 & 0 & 1 \end{bmatrix}$$

Extrinsic parameters (world-centered)



FILE VARIABLE CODE SIMULINK ENVIRONMENT RESOURCES

C: \ Users \ hspark \ Desktop \ Lecture \ calib \ image

Current Folder

- Name
- calib\_data.mat
- image000001.jpg
- image000002.jpg
- image000003.jpg
- image000004.jpg
- image000005.jpg
- image000006.jpg
- image000007.jpg
- image000008.jpg
- image000009.jpg
- image000010.jpg
- image000011.jpg
- image000012.jpg
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- image000028.jpg

Command Window

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done

Aspect ratio optimized (est\_aspect\_ratio = 1) -> both components of fc are estimated (DEFAULT).  
Principal point optimized (center\_optim=1) - (DEFAULT). To reject principal point, set center\_optim  
S Camera Calibration Toolbox - Standard Version

Image names	Read images	Extract grid corners	Calibration
Show Extrinsic	Reproject on images	Analyse error	Recomp. corners
Add/Suppress images	Save	Load	Exit
Comp. Extrinsic	Undistort image	Export calib data	Show calib results

Initialization of the intrinsic parameters - Number of images: 28

Calibration parameters after initialization:

```

Focal Length:      fc = [ 1432.81676   1432.81676 ]
Principal point:  cc = [ 1919.50000   1079.50000 ]
Skew:              alpha_c = [ 0.00000 ] => angle of pixel = 90.00000 degrees
Distortion:        kc = [ 0.00000   0.00000   0.00000   0.00000   0.00000 ]

```

Main calibration optimization procedure - Number of images: 28  
Gradient descent iterations: 1...2...3...4...5...6...7...8...9...10...11...12...13...14...15...16...  
Estimation of uncertainties...done

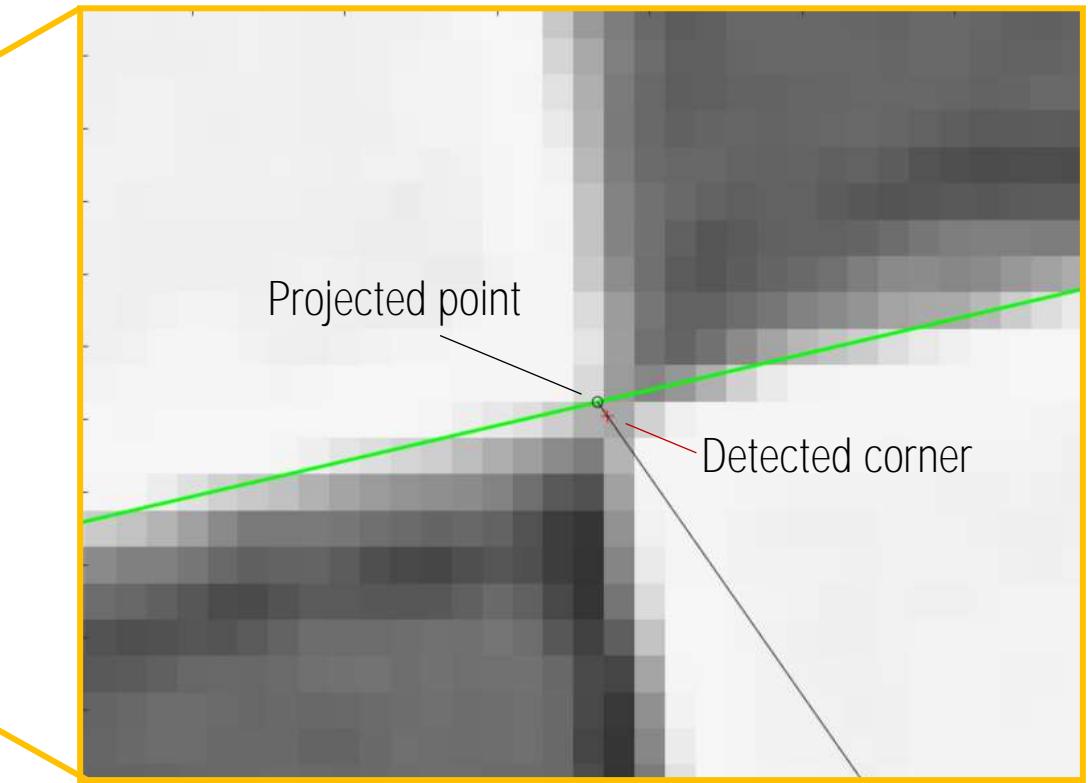
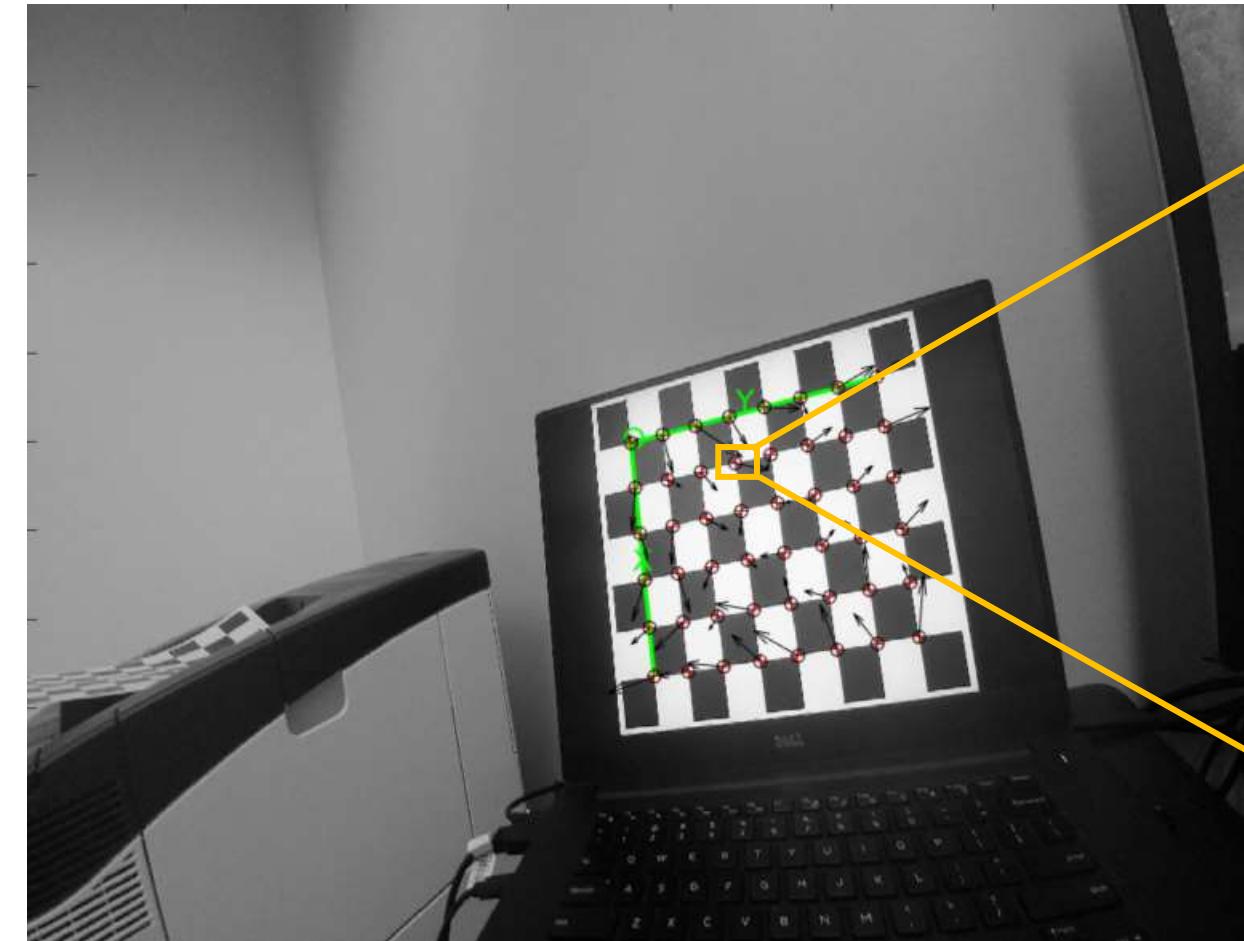
Calibration results after optimization (with uncertainties):

```

Focal Length:      fc = [ 1370.51537   1369.77187 ] +/- [ 4.43385   4.39381 ]
Principal point:  cc = [ 1951.21042   1043.25952 ] +/- [ 2.27887   2.00849 ]
Skew:              alpha_c = [ 0.00000 ] +/- [ 0.00000 ] => angle of pixel axes = 90.00000 +/- 0.
Distortion:        kc = [ -0.02790   -0.01104   -0.00060   0.00001   0.00000 ] +/- [ 0.00169   0
Pixel error:       err = [ 0.45444   0.36957 ]

```

Note: The numerical errors are approximately three times the standard deviations (for reference).





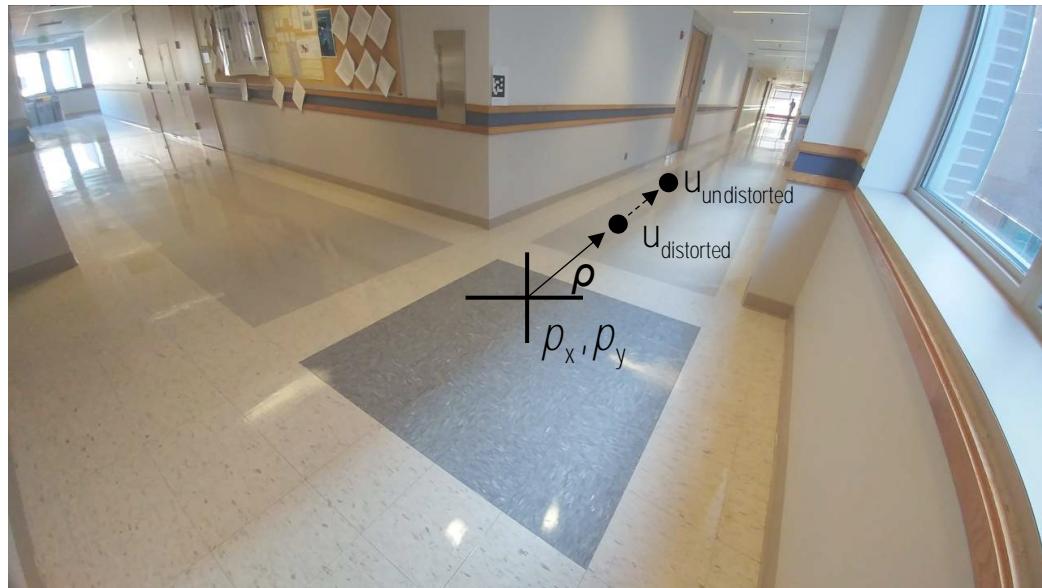
Lens Radial Distortion



Lens Radial Distortion Correction

# Radial Distortion Model

Assumption: Lens distortion is a function of distance from the principal point.

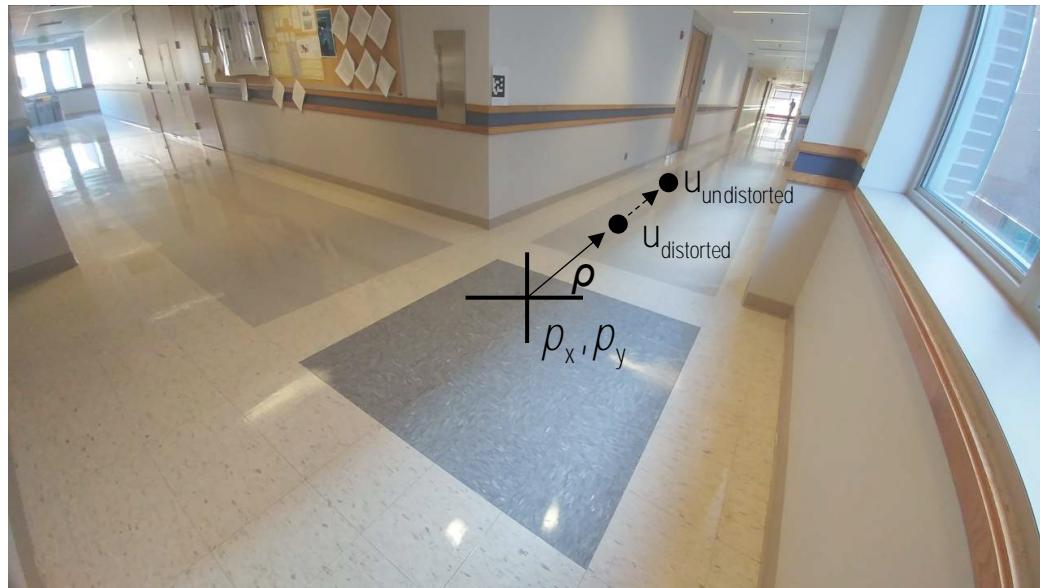


Normalized point:

$$\bar{u}_{\text{distorted}} = K^{-1}u_{\text{distorted}}, \quad \bar{u}_{\text{undistorted}} = K^{-1}u_{\text{undistorted}}$$

# Radial Distortion Model

Assumption: Lens distortion is a function of distance from the principal point.



Normalized point:

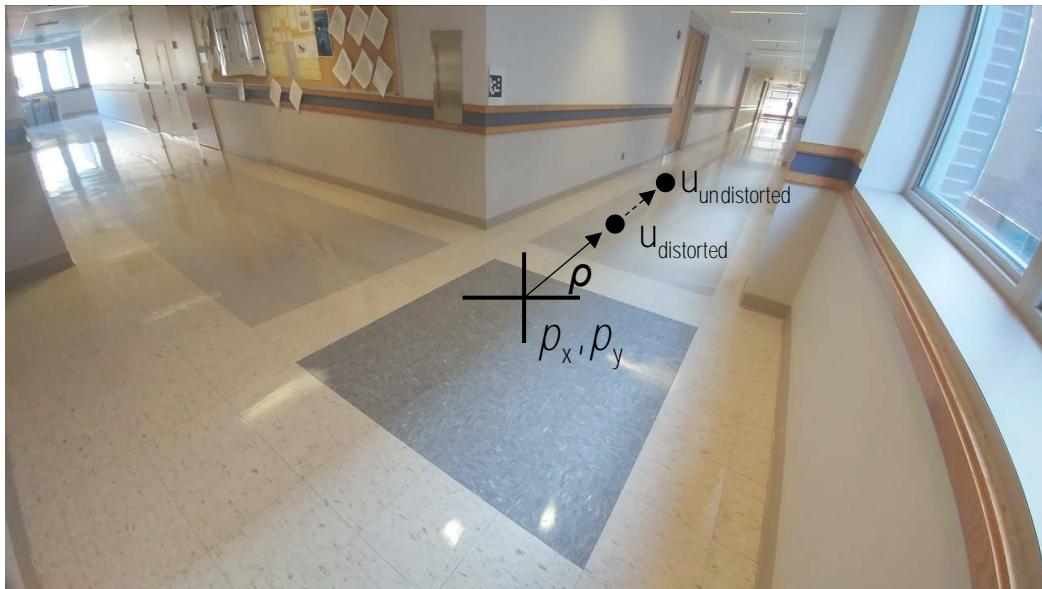
$$\bar{u}_{\text{distorted}} = K^{-1}u_{\text{distorted}}, \quad \bar{u}_{\text{undistorted}} = K^{-1}u_{\text{undistorted}}$$

$$\bar{u}_{\text{distorted}} = L(\rho)\bar{u}_{\text{undistorted}}$$

$$\text{where } \rho = \|K^{-1}\bar{u}_{\text{distorted}}\|$$

$$L(\rho) = 1 + k_1\rho^2 + k_2\rho^4 + \dots$$

# Radial Distortion Parameter Estimation (2<sup>nd</sup> order)

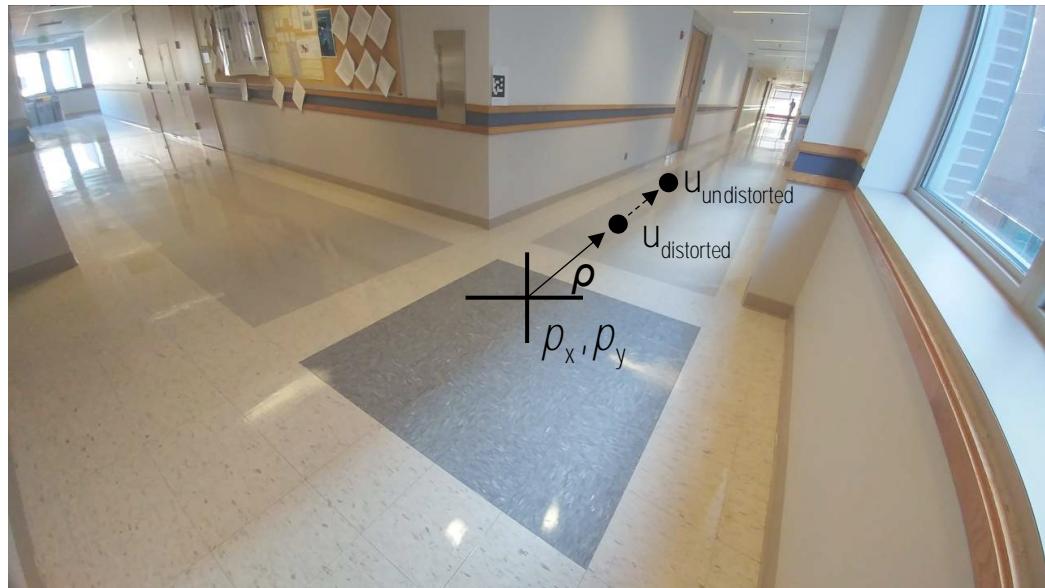


Normalized point:

$$\bar{u}_{\text{distorted}} = K^{-1}u_{\text{distorted}}, \quad \bar{u}_{\text{undistorted}} = K^{-1}u_{\text{undistorted}}$$

$$\bar{u}_{\text{distorted}} = (1 + k_1\rho^2 + k_2\rho^4)\bar{u}_{\text{undistorted}}$$

# Radial Distortion Parameter Estimation (2<sup>nd</sup> order)



Normalized point:

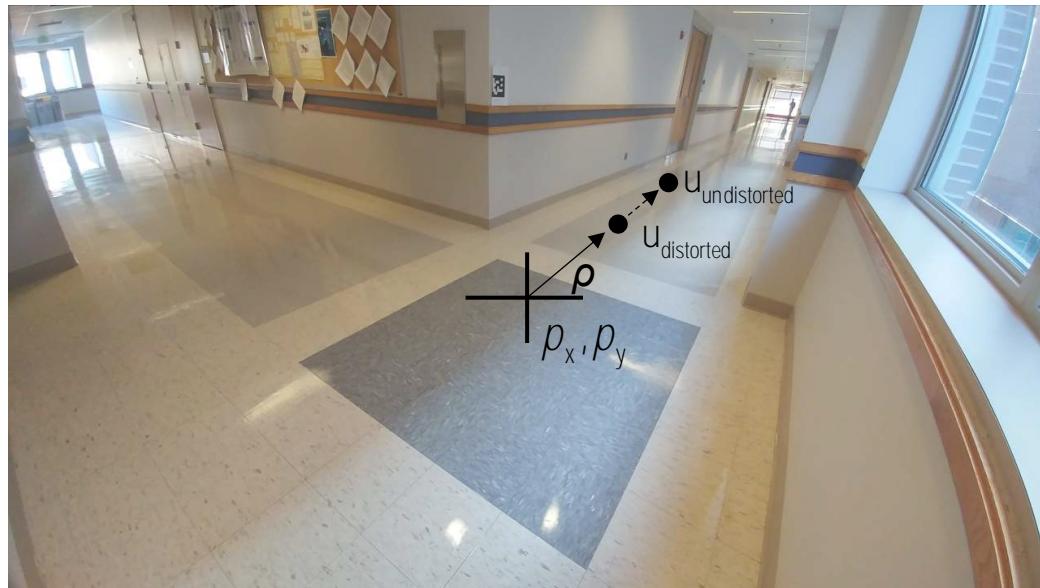
$$\bar{u}_{\text{distorted}} = K^{-1}u_{\text{distorted}}, \quad \bar{u}_{\text{undistorted}} = K^{-1}u_{\text{undistorted}}$$

$$\bar{u}_{\text{distorted}} = (1 + k_1\rho^2 + k_2\rho^4)\bar{u}_{\text{undistorted}}$$

$$\begin{bmatrix} \rho^2 \bar{u}_{\text{undistorted}}^1 & \rho^4 \bar{u}_{\text{undistorted}}^1 \\ \vdots & \vdots \\ \rho^2 \bar{u}_{\text{undistorted}}^m & \rho^4 \bar{u}_{\text{undistorted}}^m \end{bmatrix} \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \begin{bmatrix} \bar{u}_{\text{distorted}}^1 - \bar{u}_{\text{undistorted}}^1 \\ \vdots \\ \bar{u}_{\text{distorted}}^m - \bar{u}_{\text{undistorted}}^m \end{bmatrix}$$

*m: # of points*

# Radial Distortion Parameter Estimation (2<sup>nd</sup> order)



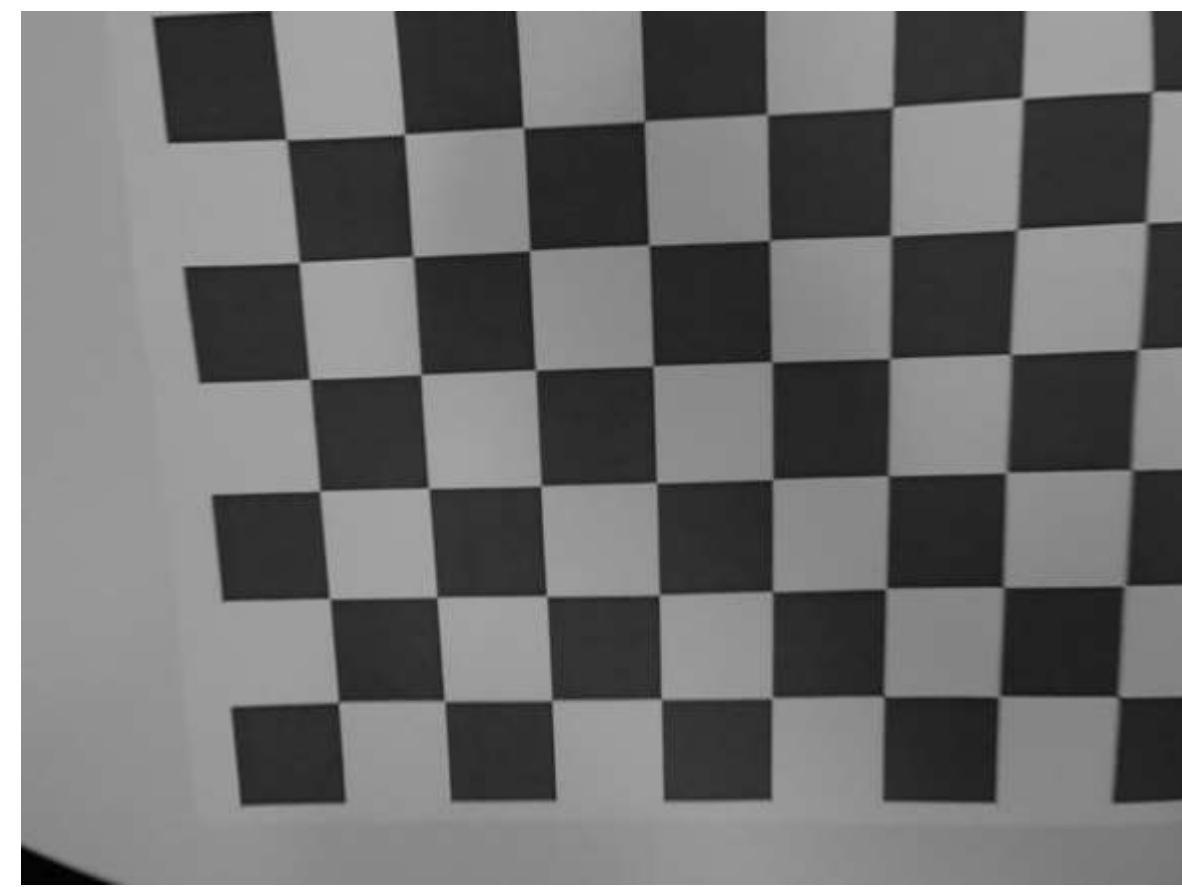
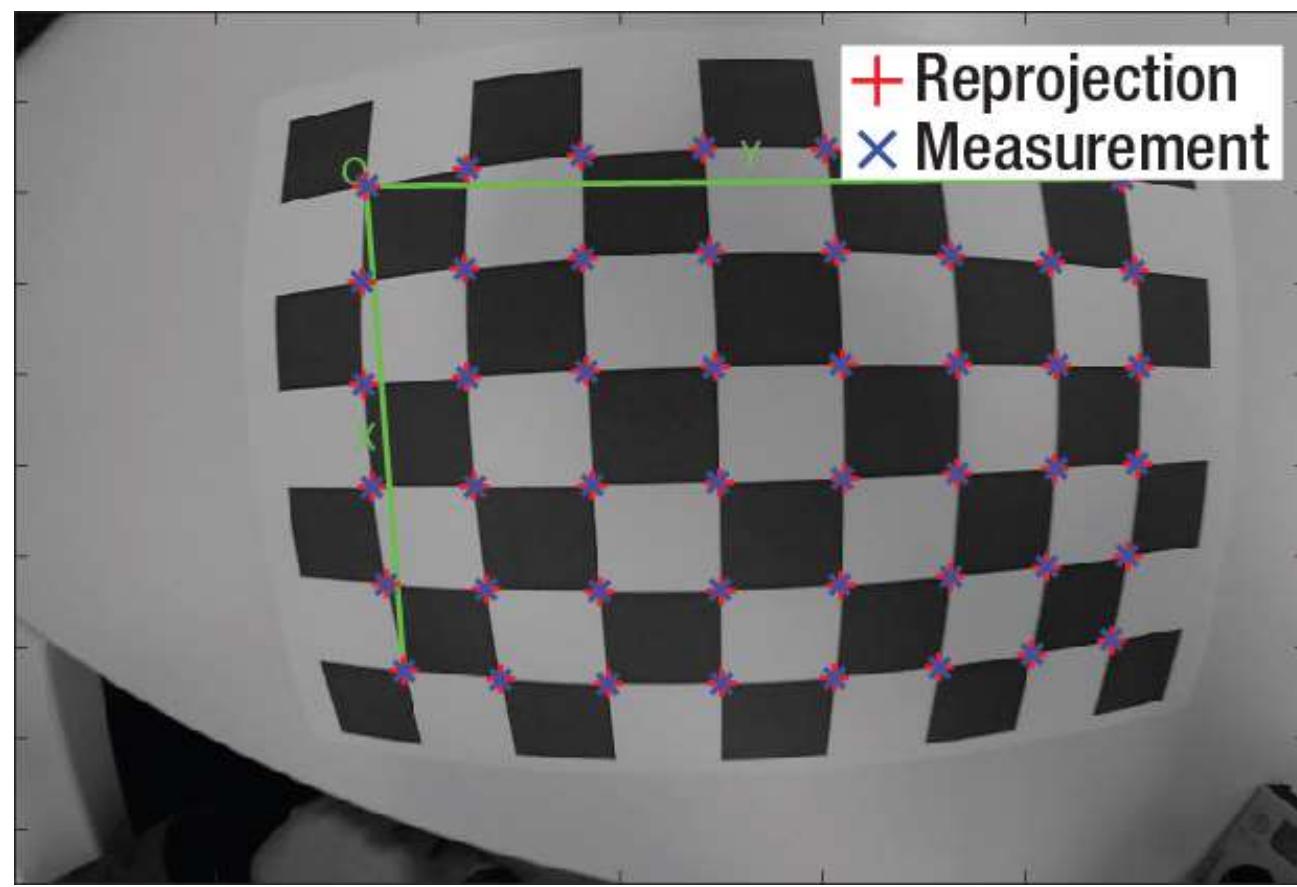
Normalized point:

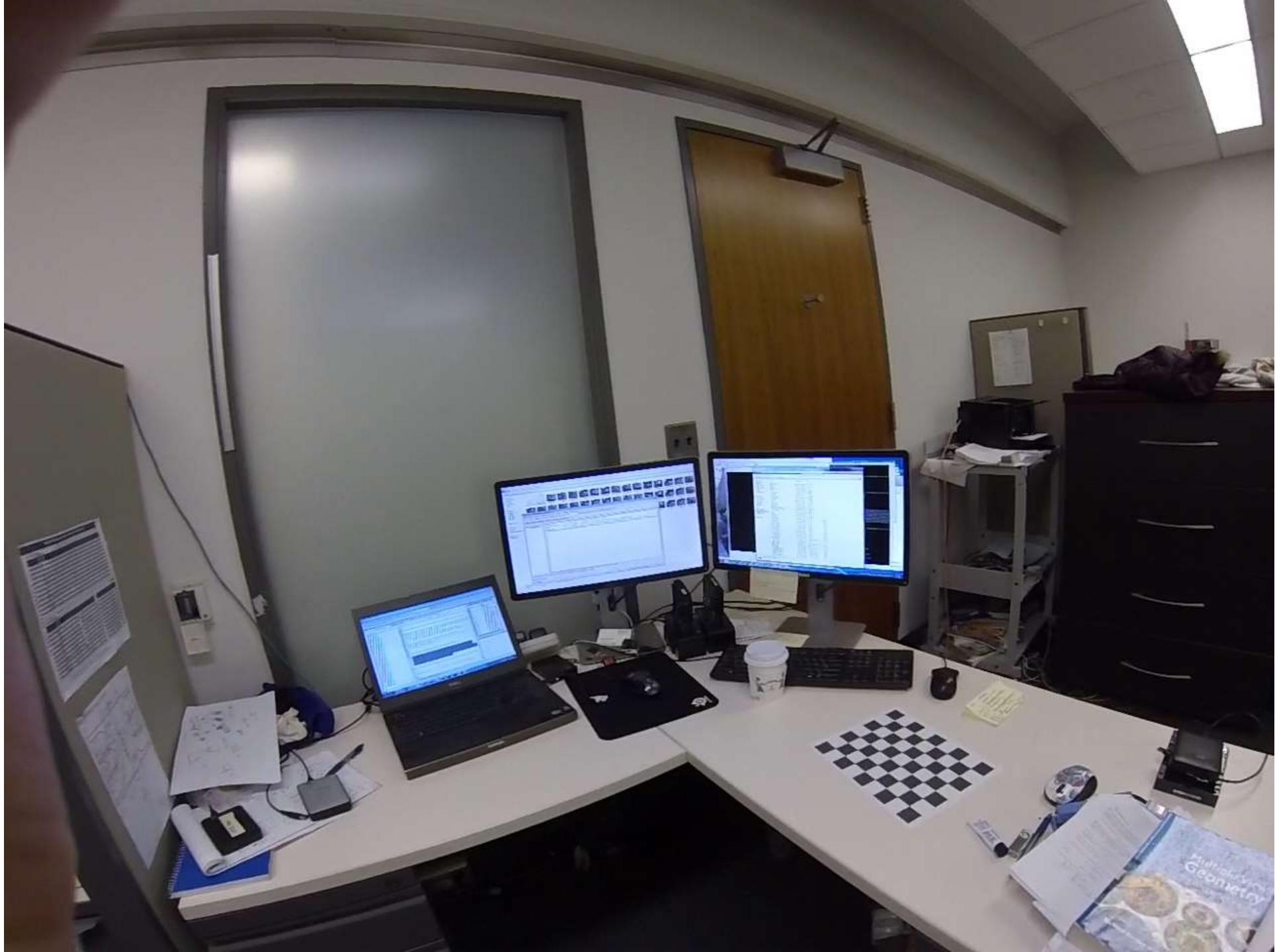
$$\bar{u}_{\text{distorted}} = K^{-1}u_{\text{distorted}}, \quad \bar{u}_{\text{undistorted}} = K^{-1}u_{\text{undistorted}}$$

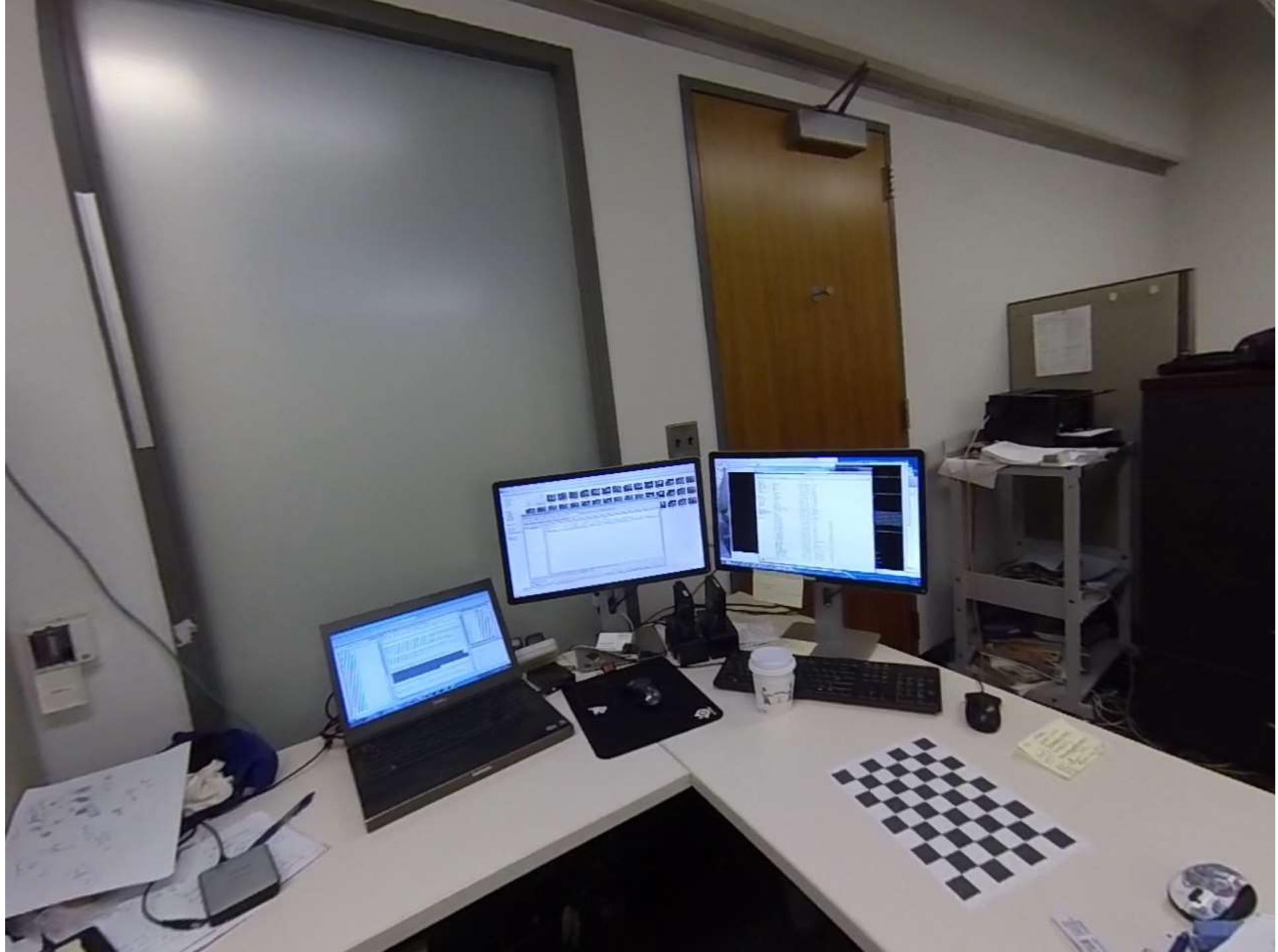
$$\bar{u}_{\text{distorted}} = (1 + k_1\rho^2 + k_2\rho^4)\bar{u}_{\text{undistorted}}$$

$$\begin{bmatrix} \rho^2 \bar{u}_{\text{undistorted}}^1 & \rho^4 \bar{u}_{\text{undistorted}}^1 \\ \vdots & \vdots \\ \rho^2 \bar{u}_{\text{undistorted}}^m & \rho^4 \bar{u}_{\text{undistorted}}^m \end{bmatrix} \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \begin{bmatrix} \bar{u}_{\text{distorted}}^1 - \bar{u}_{\text{undistorted}}^1 \\ \vdots \\ \bar{u}_{\text{distorted}}^m - \bar{u}_{\text{undistorted}}^m \end{bmatrix}$$

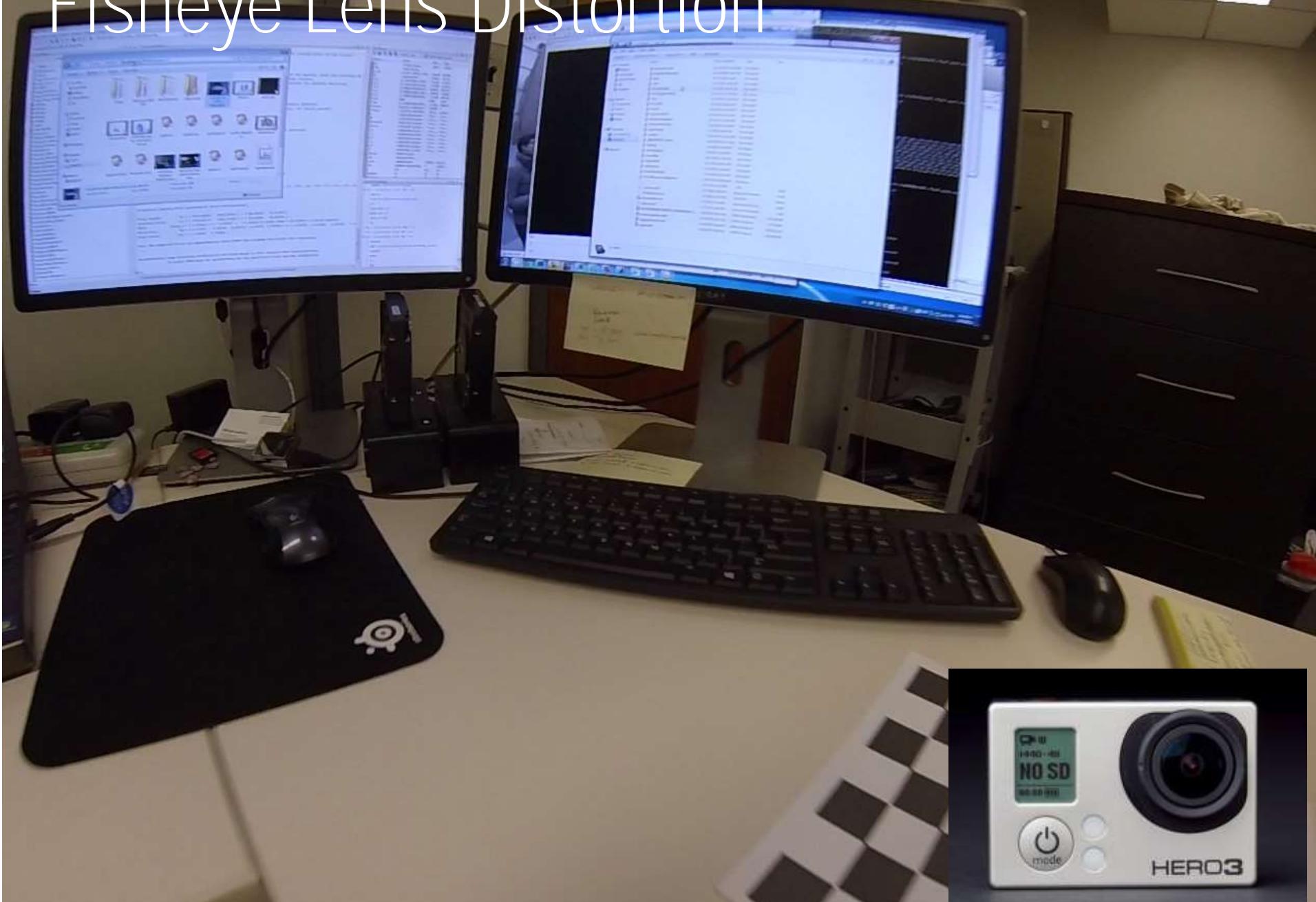
*m: # of points*







# Fisheye Lens Distortion



# Fisheye Lens Distortion

