Camera Calibration

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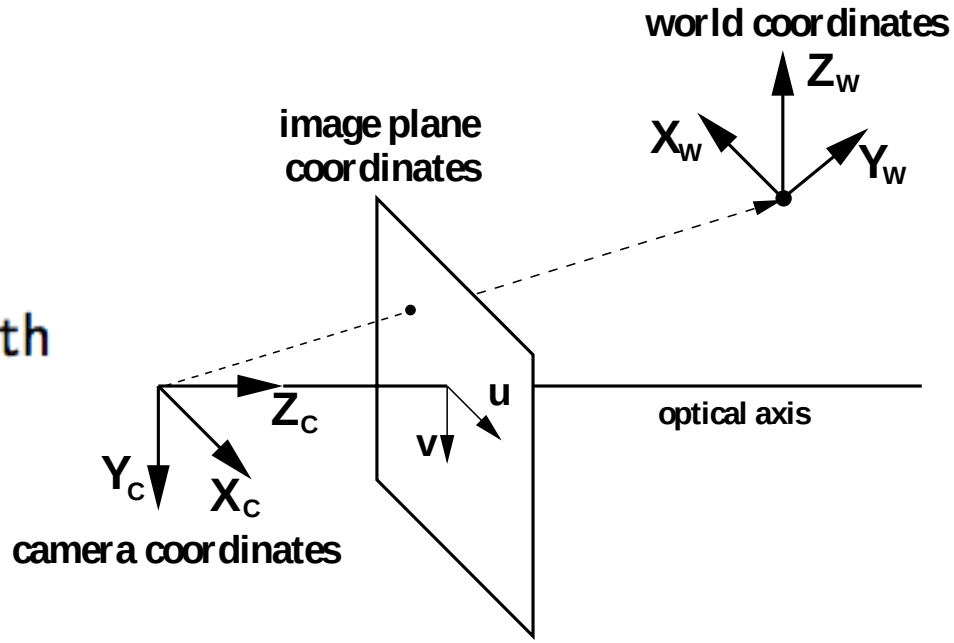
The 3x4 projection matrix P

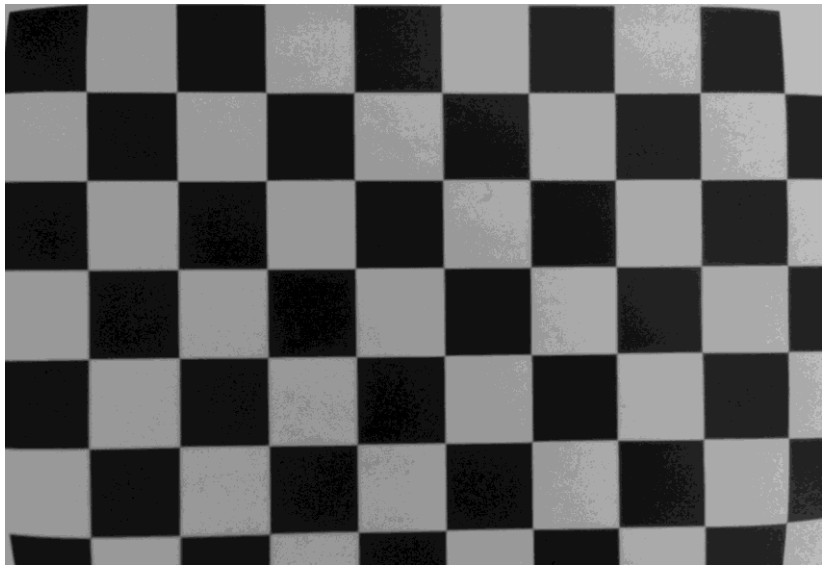
$$\lambda \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} f & 0 & u_o \\ 0 & f & v_o \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} R & t \end{pmatrix} \begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix} = P \begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix}$$

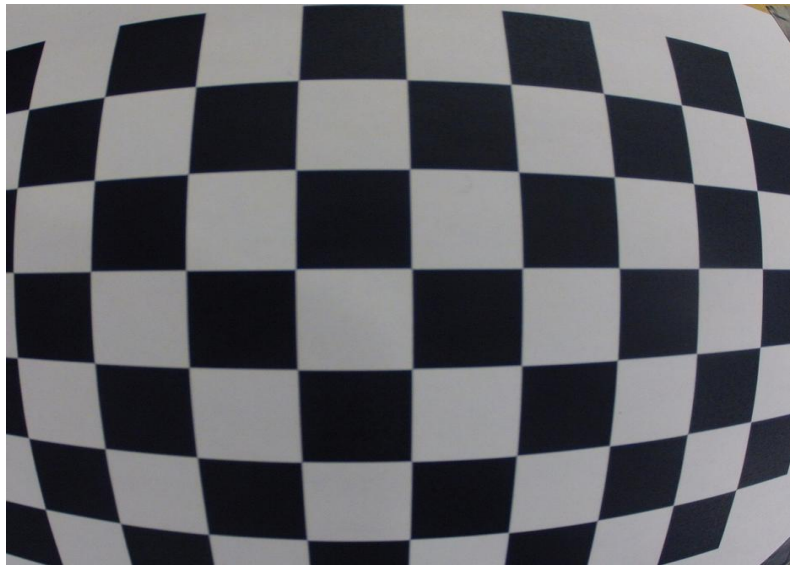
λ is the unknown depth



Cameras with large field of view have radial distortions

$$
\begin{aligned}
u^{dist} &= u(1 + k_1 r + k_2 r^2 + k_3 r^3 + \ldots) \\
v^{dist} &= v(1 + k_1 r + k_2 r^2 + k_3 r^3 + \ldots) \\
\text{where} \quad r^2 &= u^2 + v^2
\end{aligned}
$$

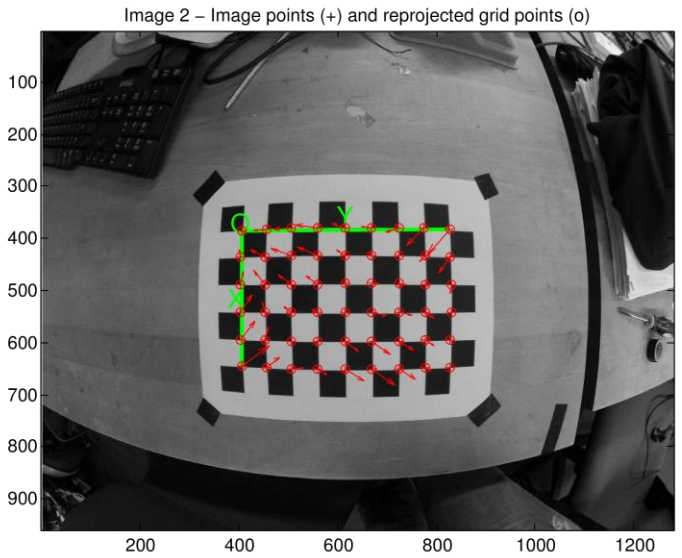


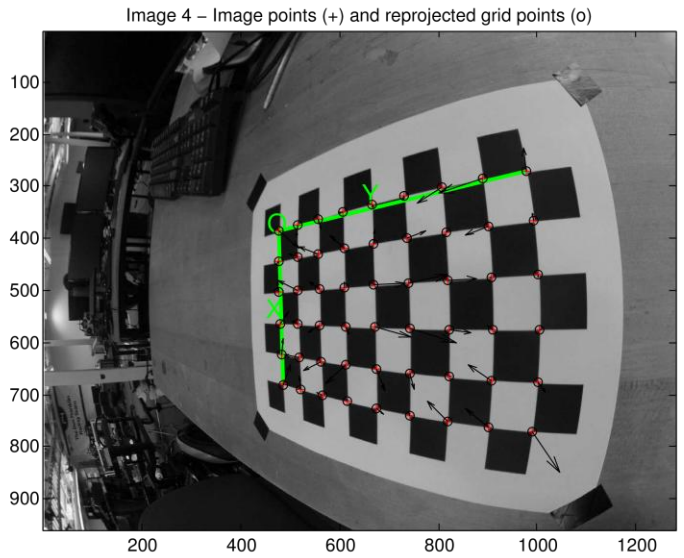


A procedure called calibration

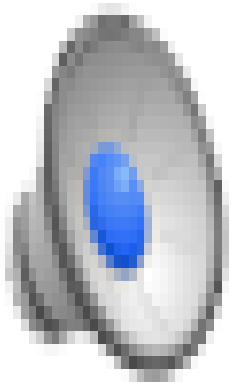
Estimates the *intrinsic parameters*

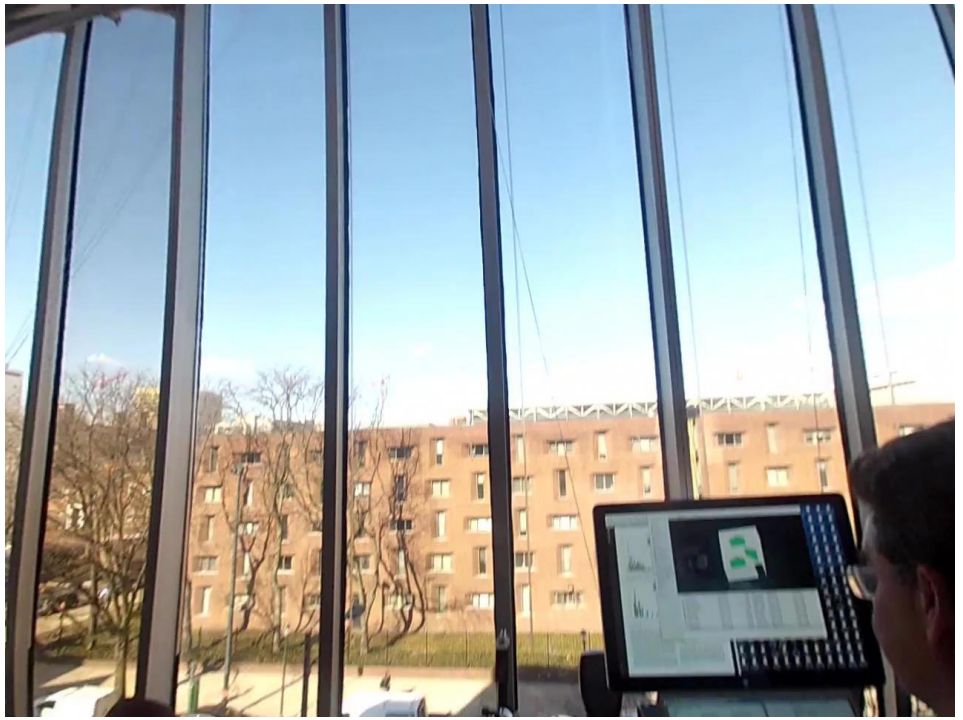
- f focal length
- (u_o, v_o) image center
- $k_1, k_2, \ldots$ radial distortion parameters



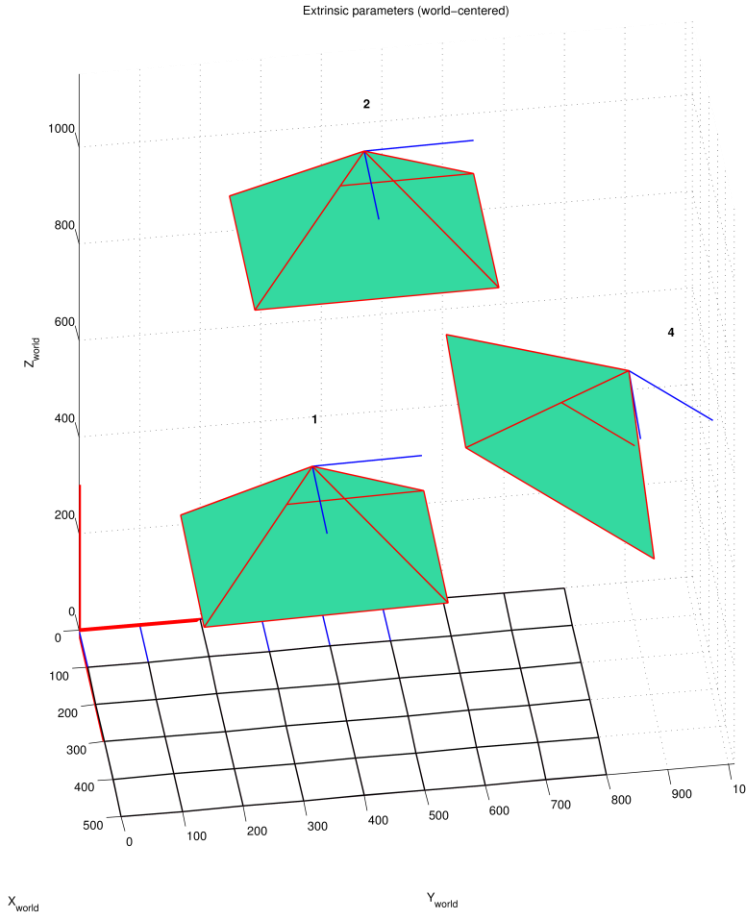


As a result of the calibration we have undistorted images and video





..as well as the poses of the camera and the projection rays in world coordinates

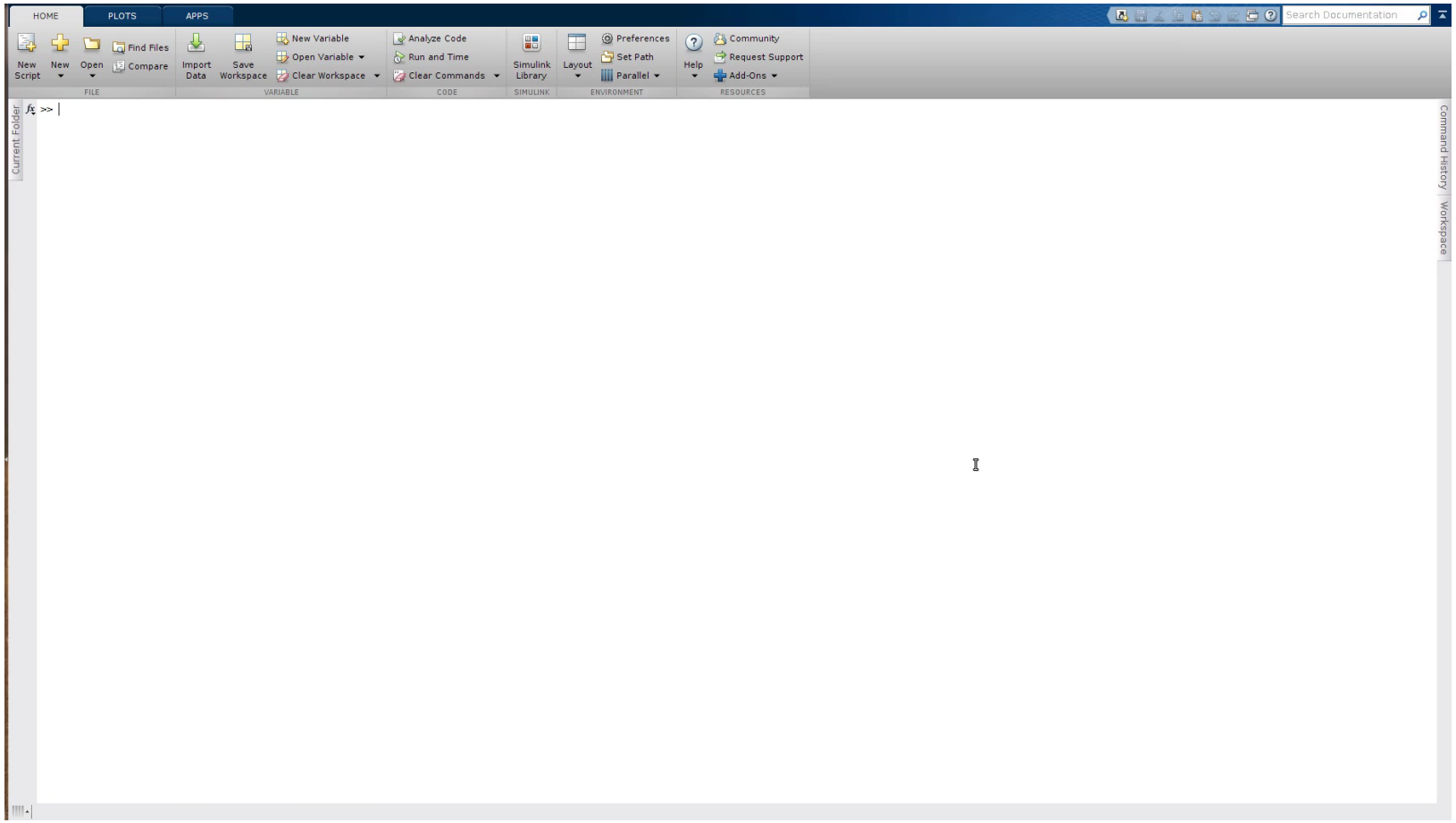


$$\begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = -R^T T + \lambda R^T K^{-1} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix}$$

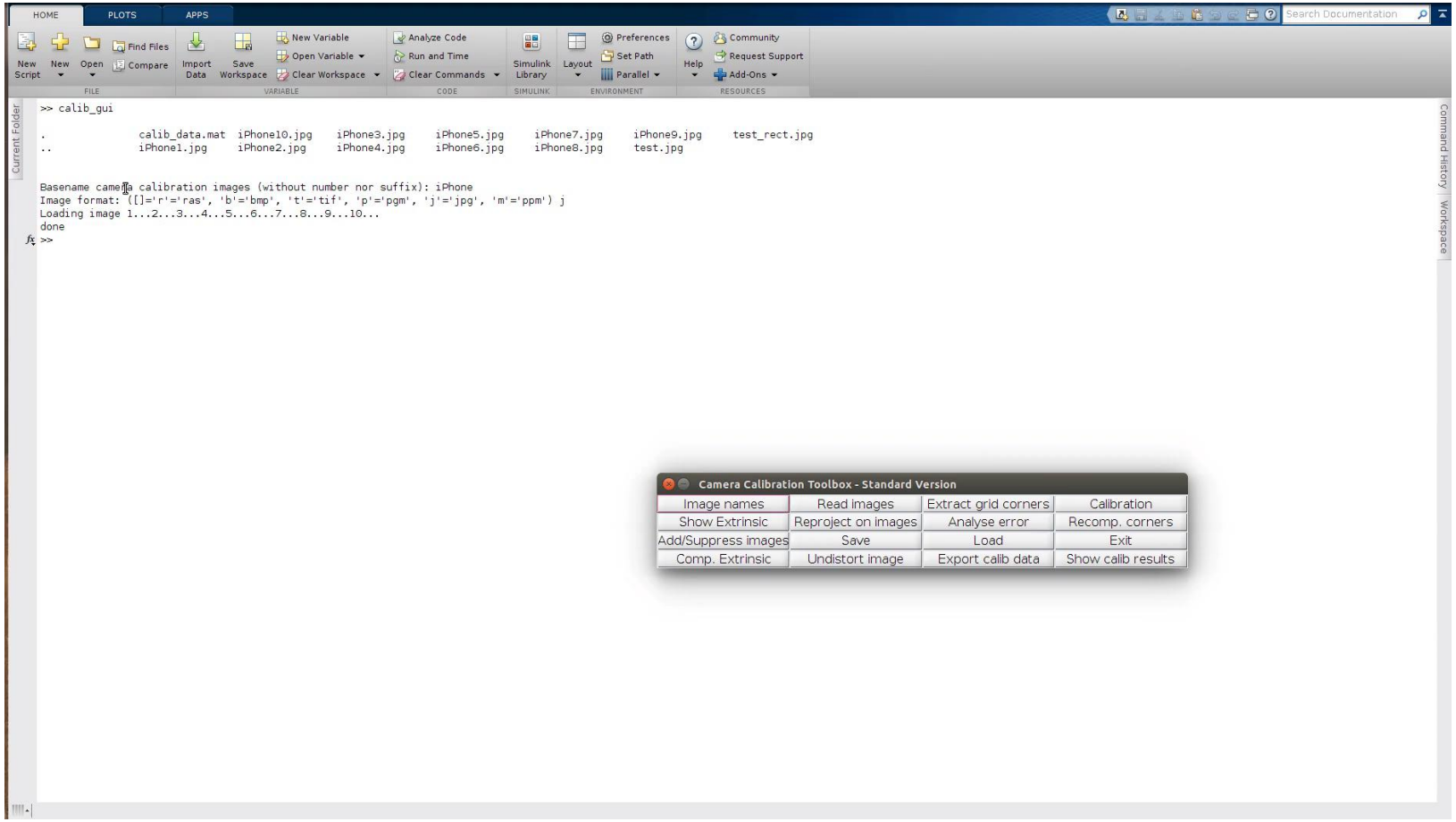
known

We will return later on the specifics of calibration….

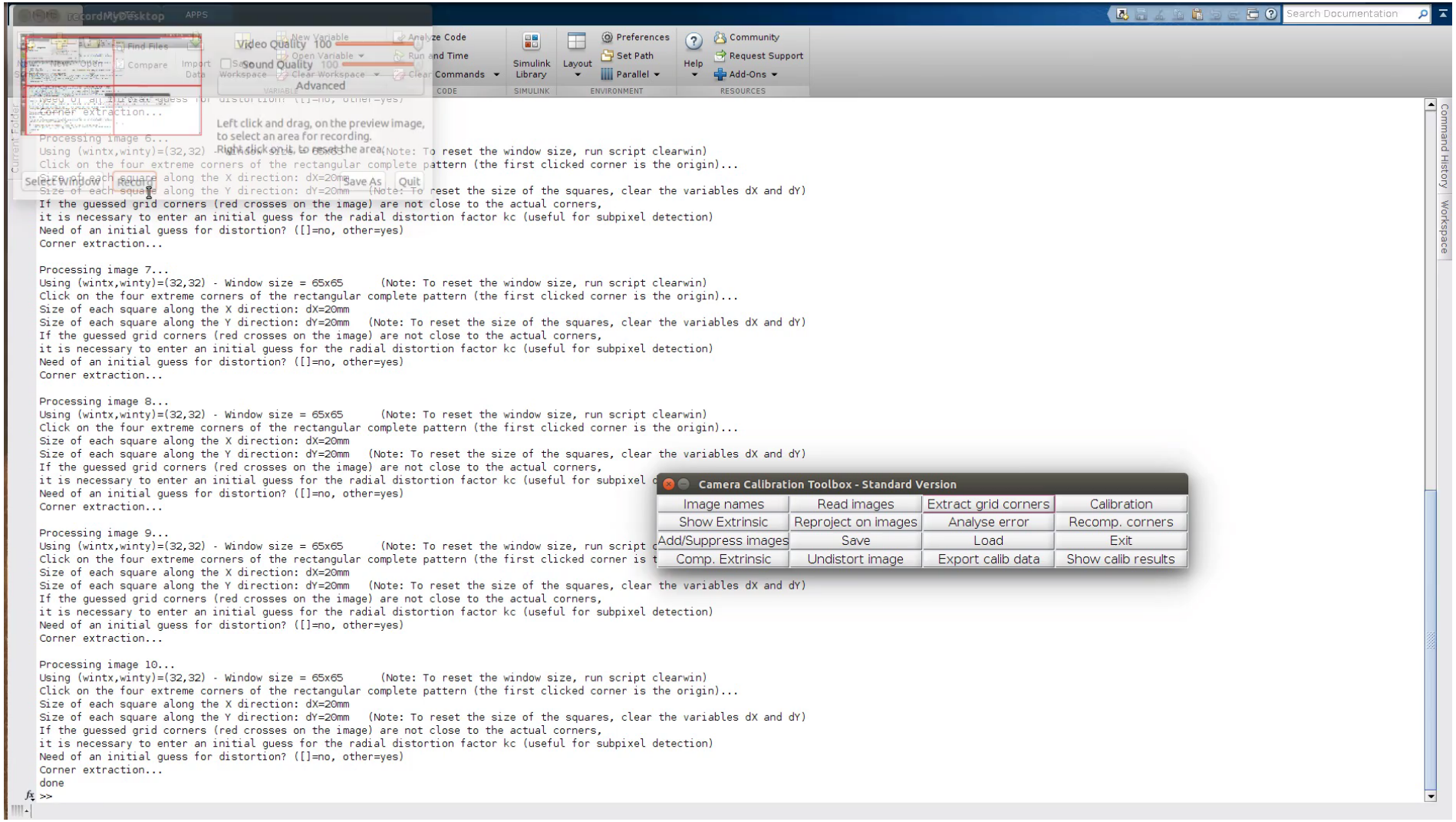
How we calibrate in Matlab?



Extracting corners of the checkerboard



Extrinsic parameter results (R,T)



Extrinsic parameter results (R,T)

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Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 3468.99207   3458.27097 ] +/- [ 10.59701   10.40724 ]
Principal point:       cc = [ 2029.63006   1511.12039 ] +/- [ 7.55158   7.25687 ]
Skew:             alpha_c = [ 0.00000 ] +/- [ 0.00000  ]   => angle of pixel axes = 90.00000 +/- 0.00000 degrees
Distortion:            kc = [ 0.07878   -0.07501   -0.00072   0.00094  0.00000 ] +/- [ 0.00520   0.01581   0.00073   0.00085  0.00000 ]
Pixel error:          err = [ 0.54275   0.61021 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).
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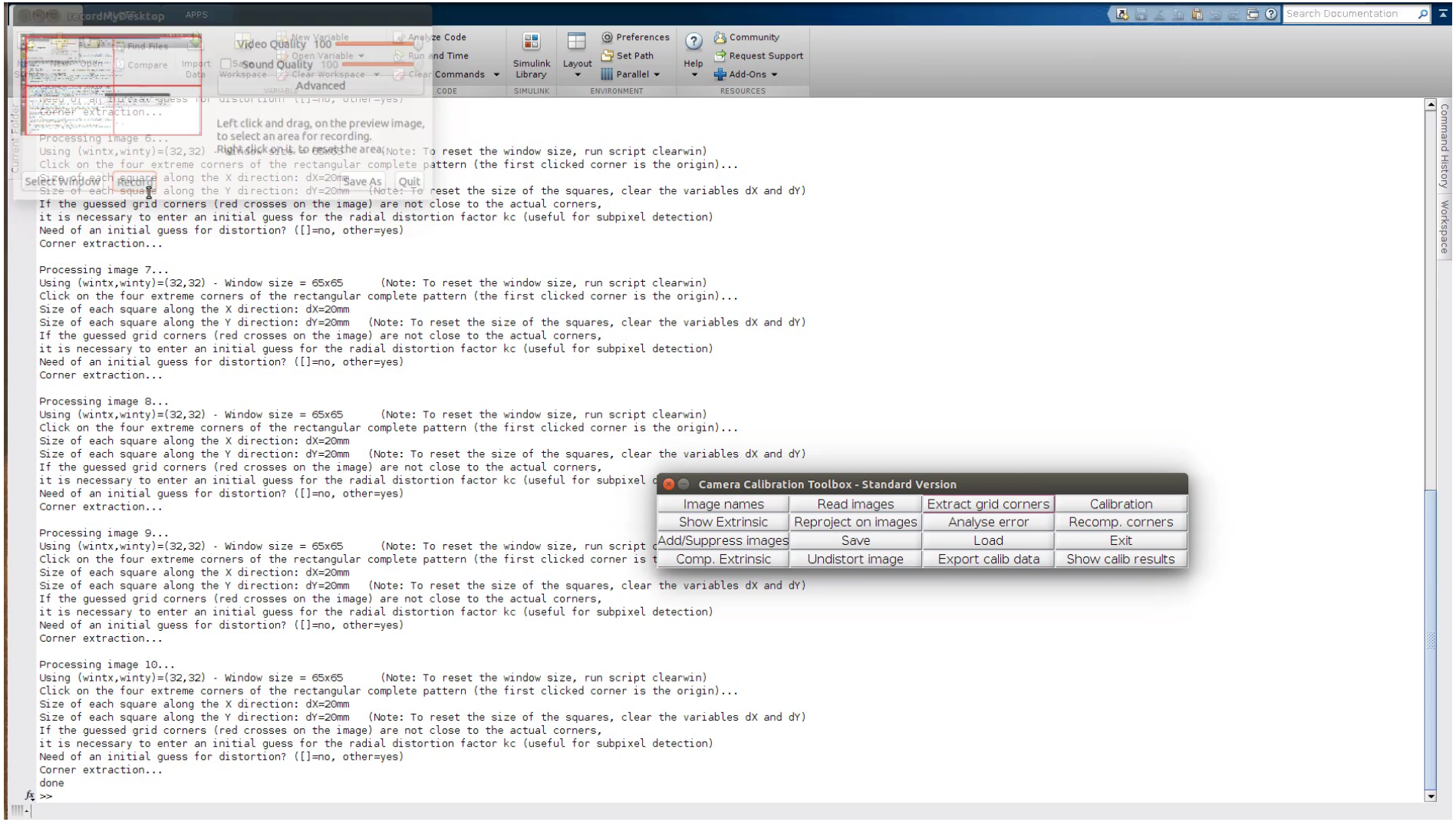
Extrinsic parameter results (R,T)



Reproject undistorted coordinates