SAND2015-4426C

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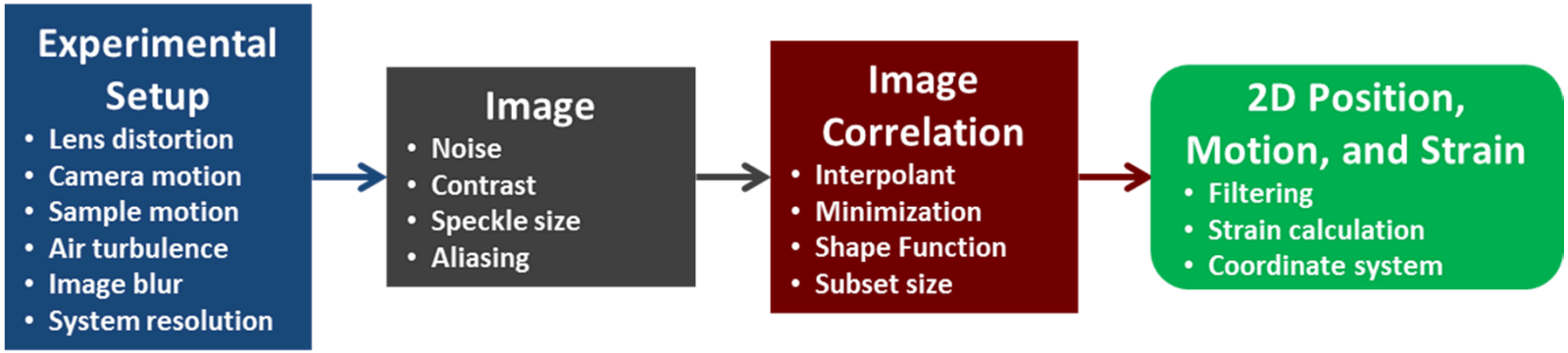

A realistic error budget for 2D-DIC

Do you have an error budget?

Phillip L. Reu
Presented by: Dan Turner or Marcia Cooper

SEM June 2015 – Costa Mesa, California

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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Two types of errors: Random and Systematic

Accurate but not Precise

Large *Random* Error

Small *Systematic* Error

Noise, repeatability,

Aleatoric Uncertainty

Precise but not Accurate

Small *Random* Error

Large *Systematic* Error

Bias Error

Epistemic uncertainty

The new view is to categorize as:

Type A and **Type B** Errors.

Why no bias errors? A known bias is removed and it becomes a variance error.

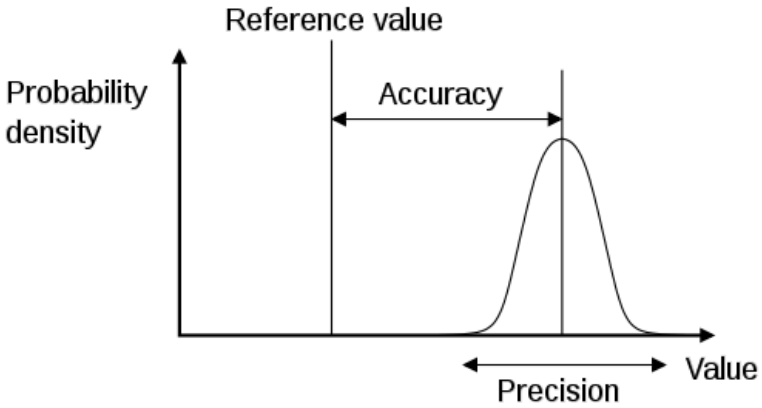

Image from Wikipedia

A newer approach categorizes errors into two types: Type A and Type B

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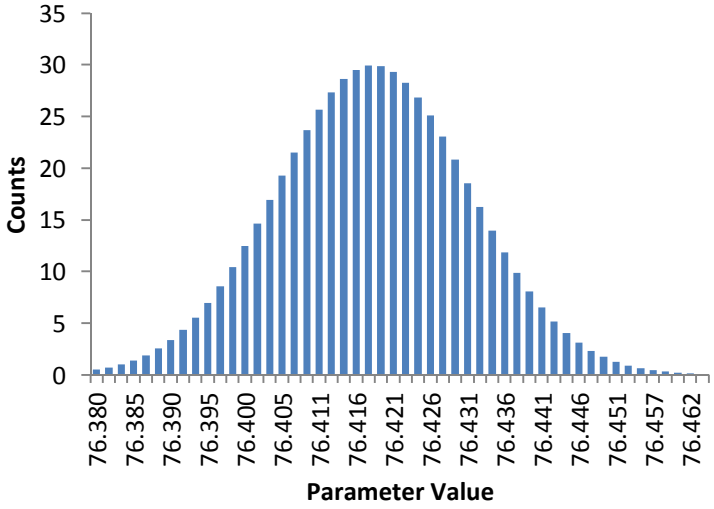
Type A – Evaluated via statistical methods
- Repeated measurements
- Statistical distributions
  - Normal, Log-normal, etc.

Type B – Evaluated by other means
- Modeling approaches
- Assumed probability distribution
- Experimental expertise



$Y = f(X_1, X_2, \ldots, X_N)$

The measurand Y is made up of X other input quantities. The function may be so complicated that it cannot be written down (Section 4.1.2).

Mathematical modeling of the experiment taking into account all error sources is a valid and approved method of estimating uncertainty. (Section 3.4.1)

BIPM (2008). "Evaluation of measurement data…" JCGM 100:2008.

Are you worrying about the wrong error source?

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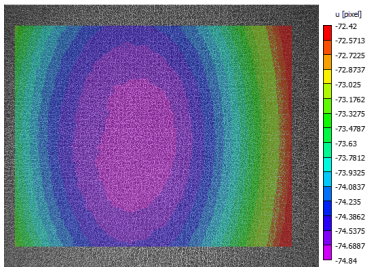
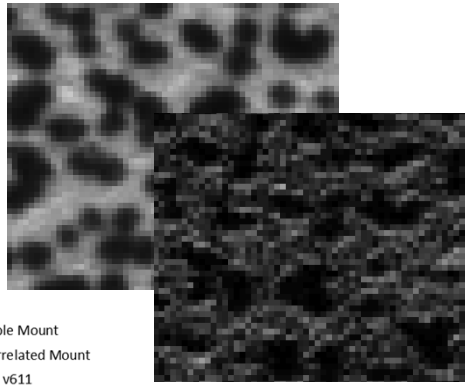
Experimental Setup
- Lens distortion
- Camera motion
- Sample motion
- Air turbulence
- Image blur
- System resolution

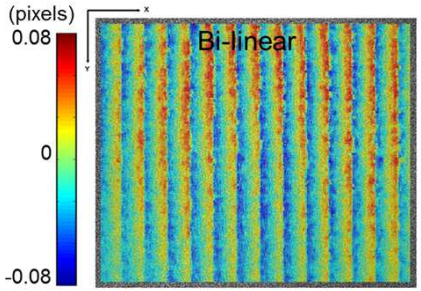
Image Acquisition
- Noise
- Contrast
- Speckle size
- Aliasing

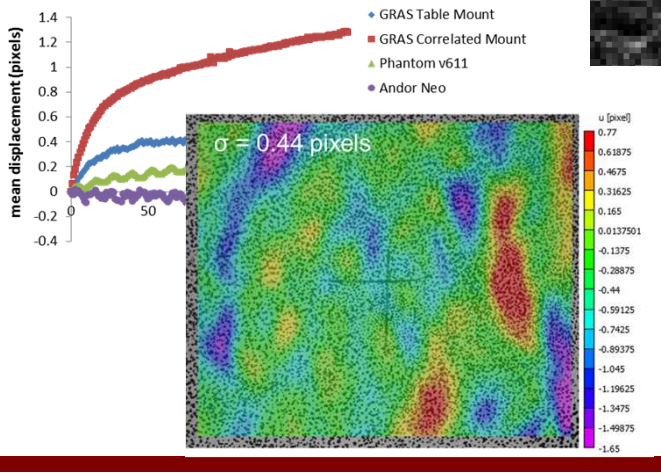
Image Correlation
- Interpolant
- Minimization
- Shape Function
- Subset size

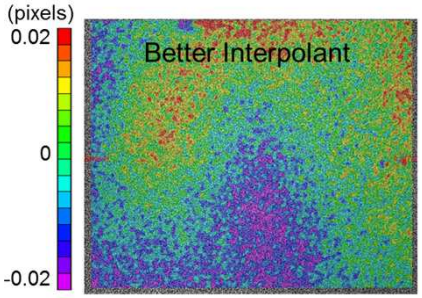
2D Position, Motion, and Strain
- Filtering
- Strain calculation
- Coordinate system



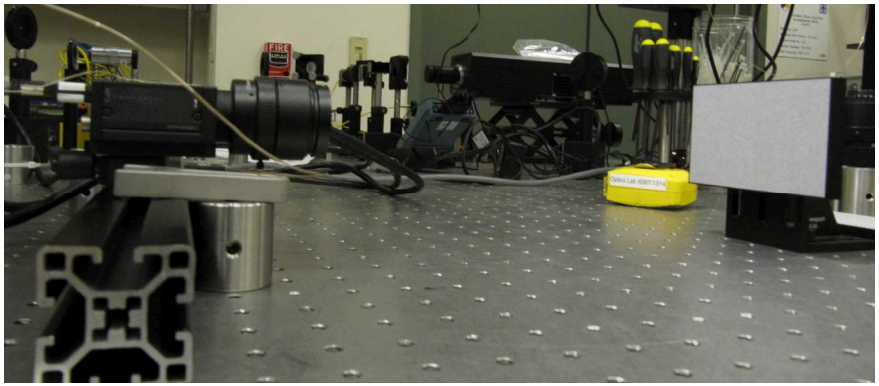


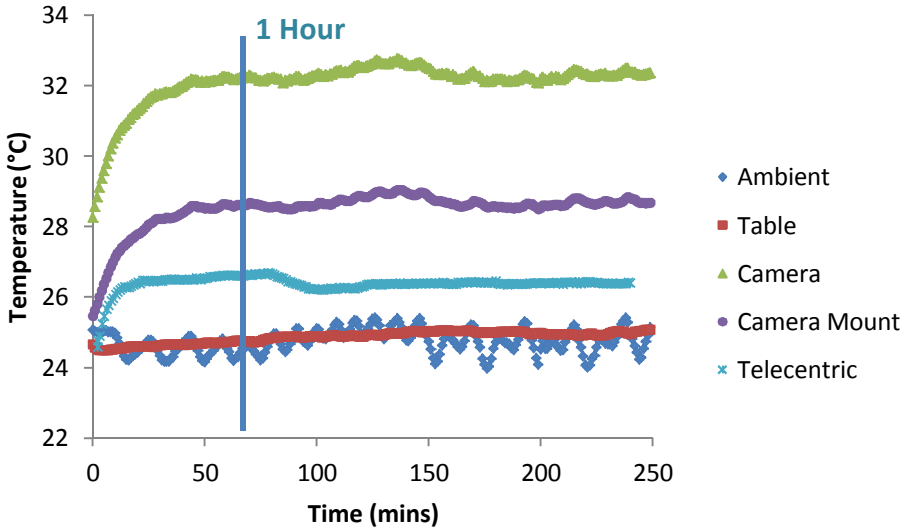


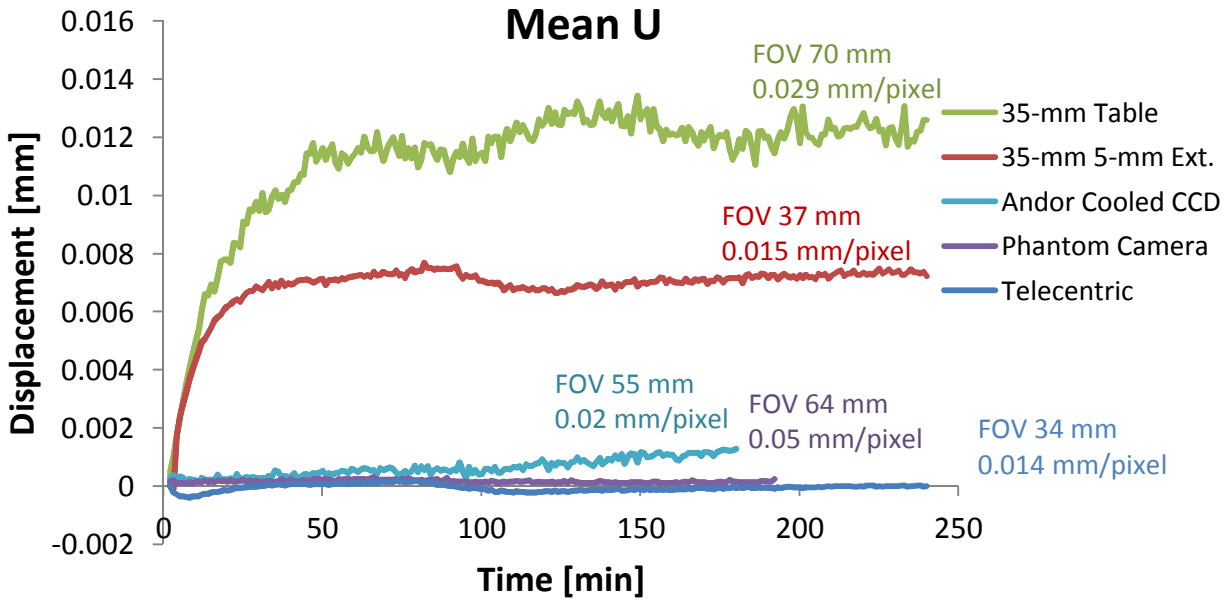




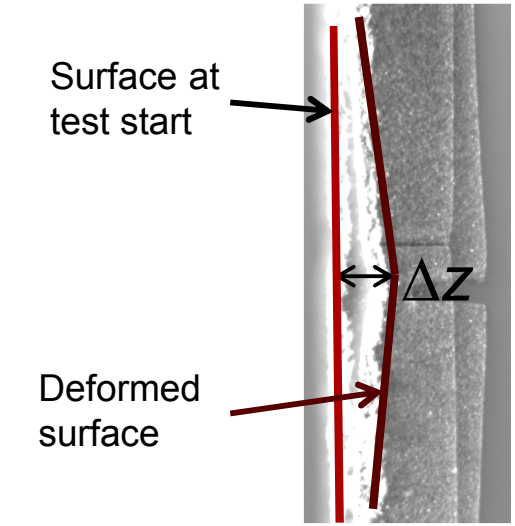
The camera will move due to a variety of sources.

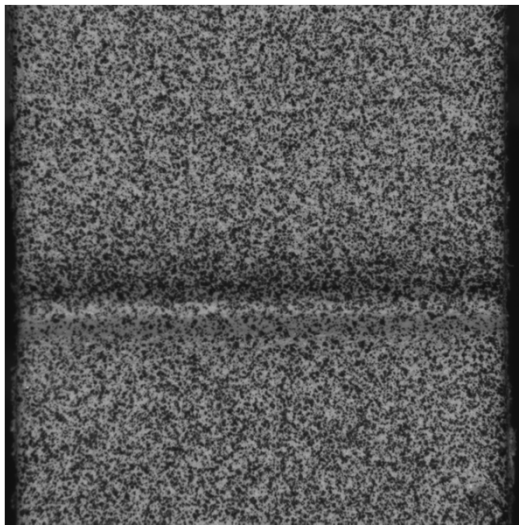






Bi-Telecentric lens will aid in removing out-of-plane errors.

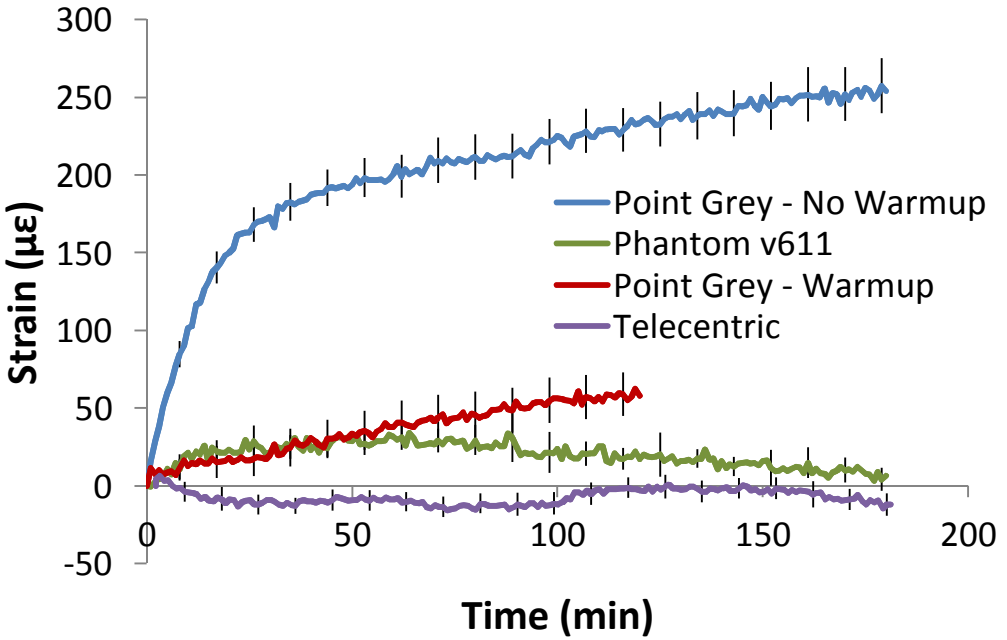


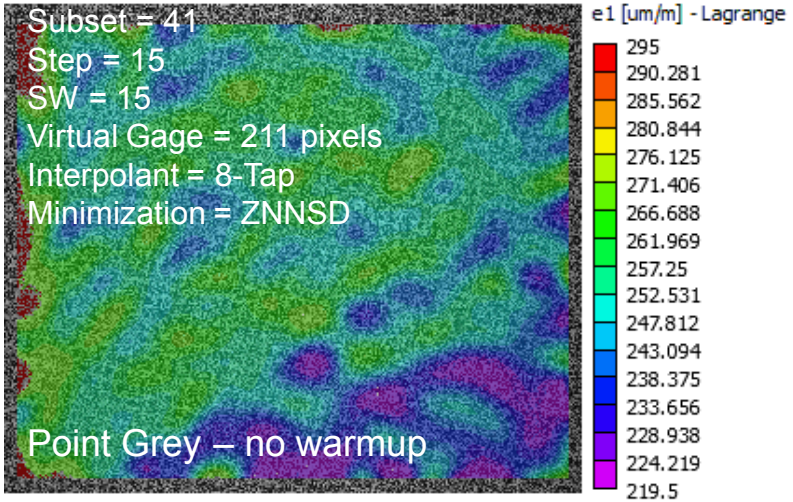


$$\varepsilon_{error} = -\frac{\Delta z}{z_{effective}}$$

Max out-of-plane, Δz = 0.41 mm

$\Delta\varepsilon \cong 0.41/200 = -0.0021 = -2100\ \mu\epsilon$

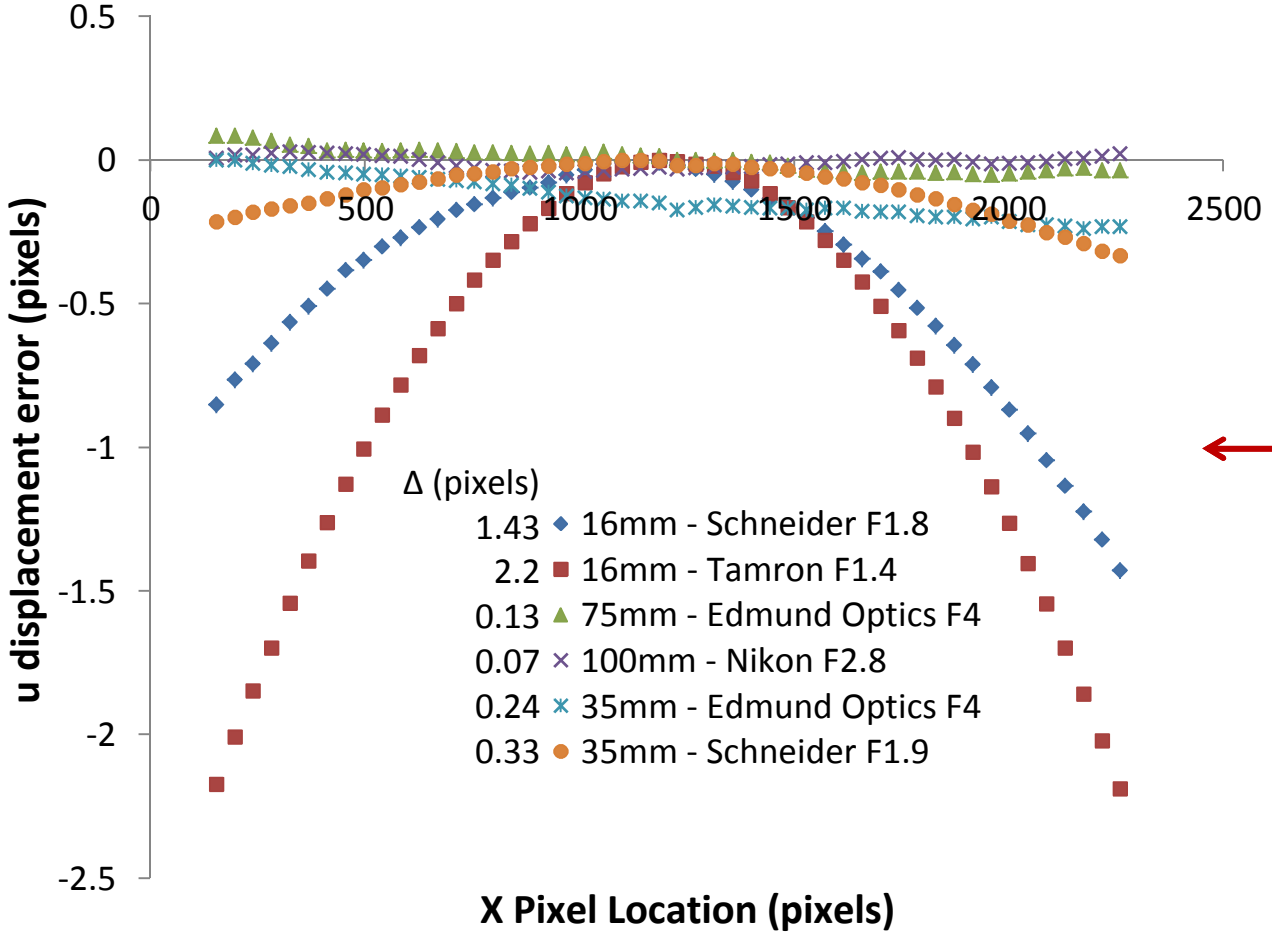


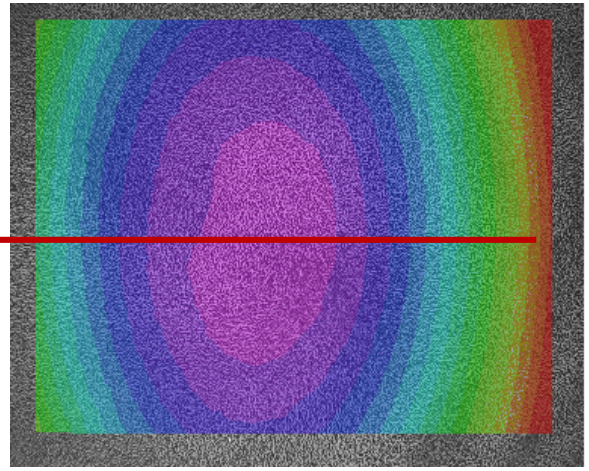


Sutton, M. A., et al. (2008). Optics and Lasers in Engineering **46(10): 746-757.**

Pan, B., et al. (2014). Applied Optics **53(19): 4216-4227**

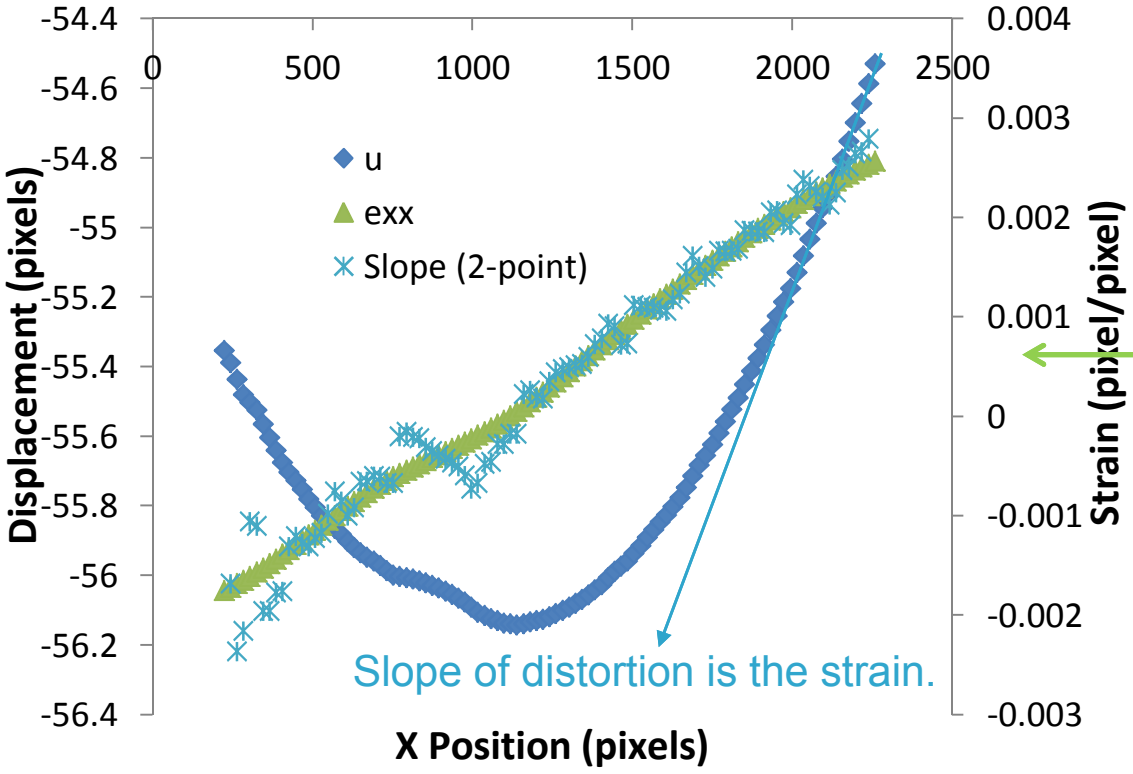
Lens distortions may cause problems with the displacement results.

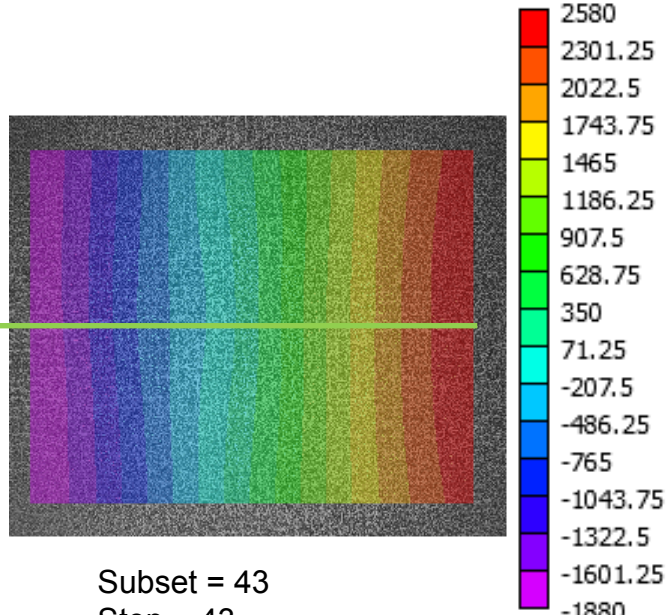




A 50 pixel shift yields a 2 pixel error at the edges.

The slope of the distortion curve also means there will be a strain error.





Subset = 43
Step = 43
SW = 15
Virtual Gage = 603 pixels
Interpolant = 8-Tap
Minimization = ZNNSD

This is a 55 pixel shift – easily done in a tensile test with stretchy materials.

Quantifying the noise of the camera and results may include camera shake.

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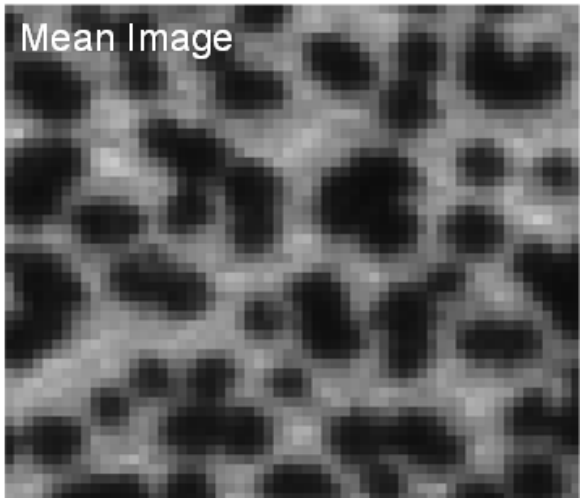
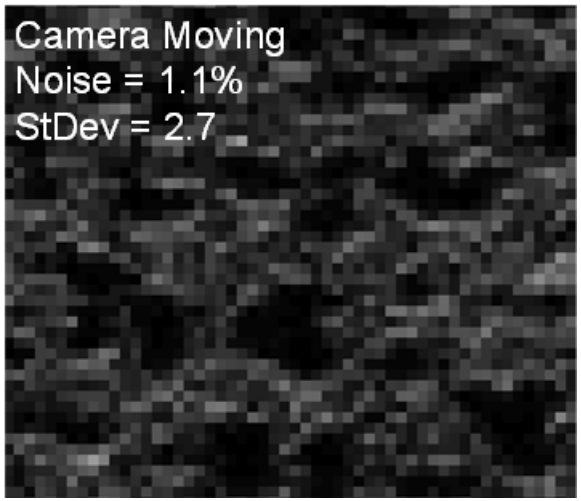
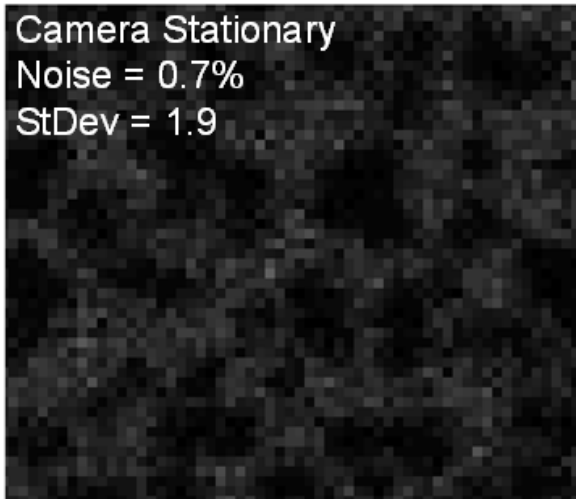
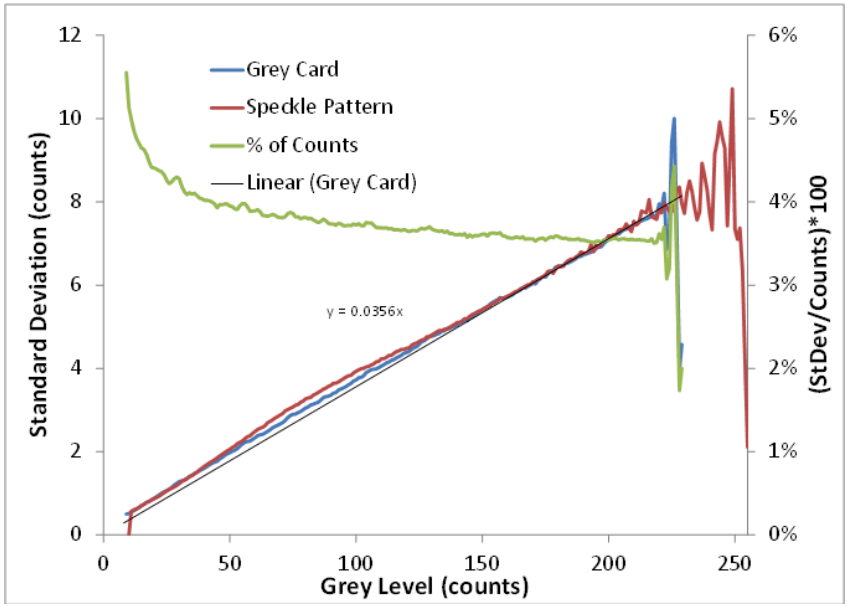
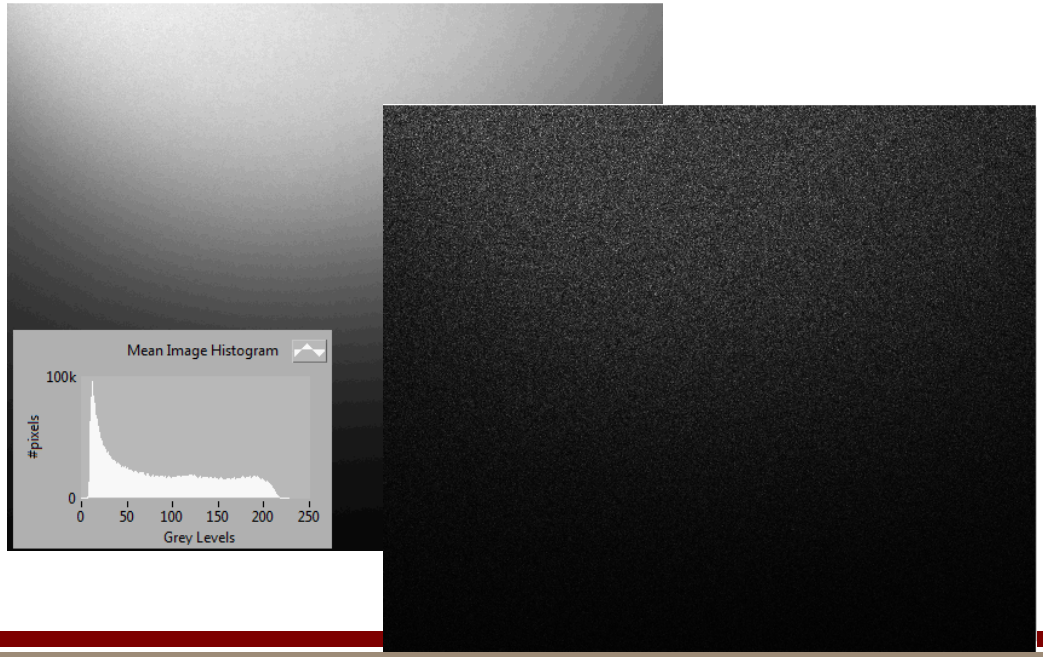




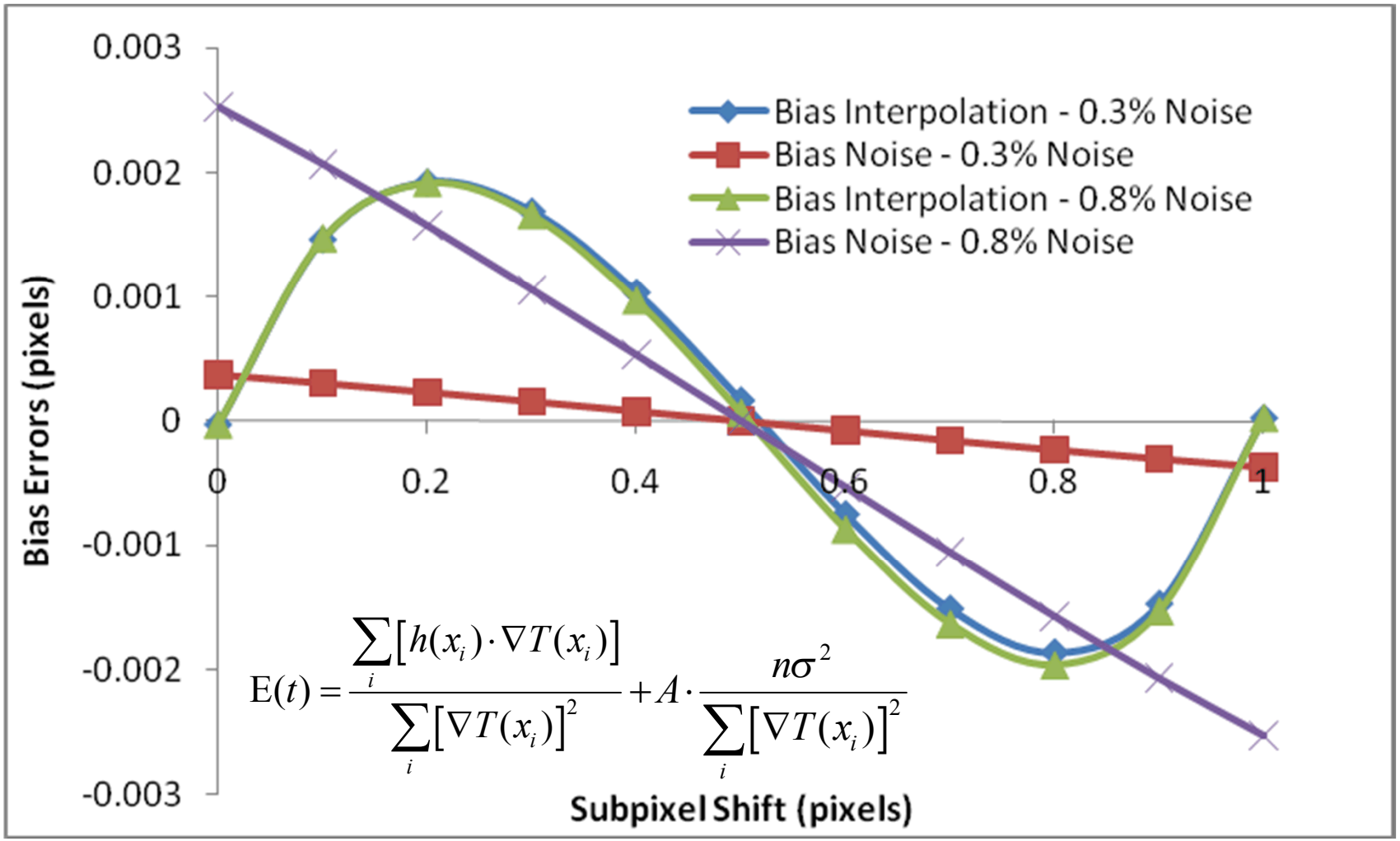






Sur, F. and M. Grediac (2014). IEEE Signal Proc. Letters 21(4): 432-436.

Bias and noise errors calculated in software agree with earlier publications



Experimentally finding the bias errors is difficult.

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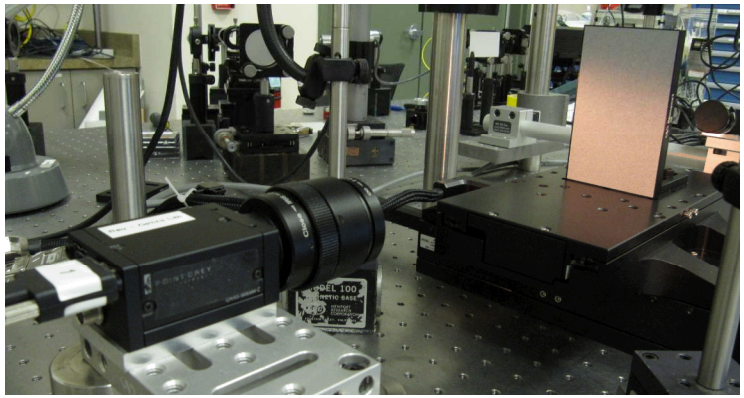
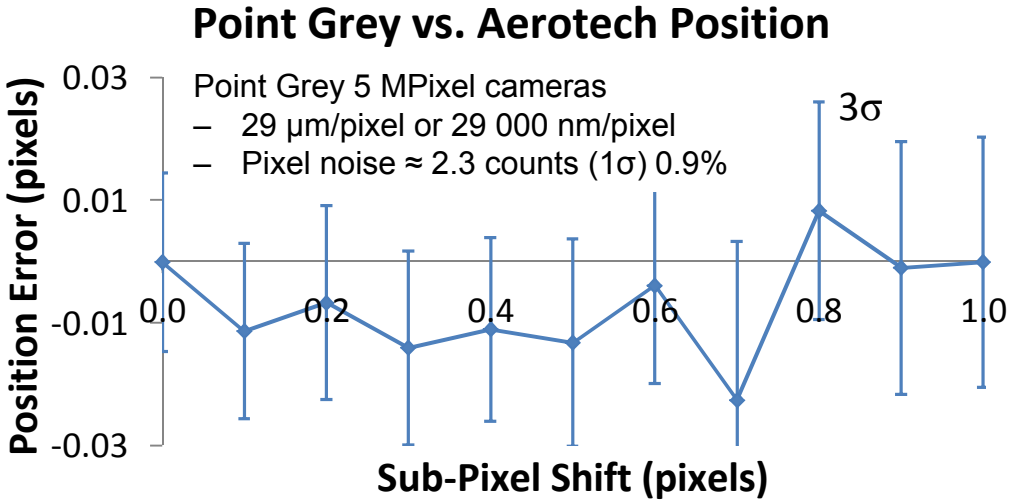
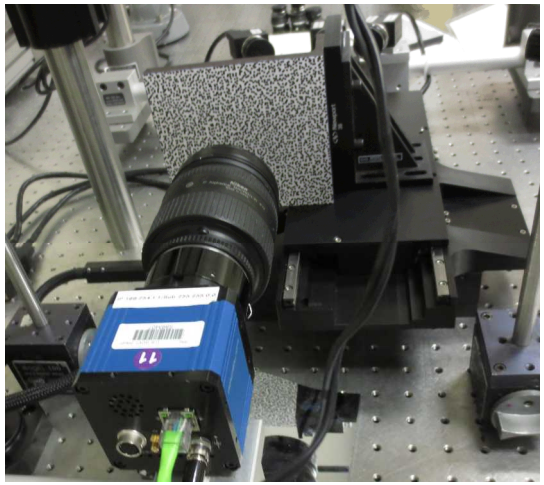
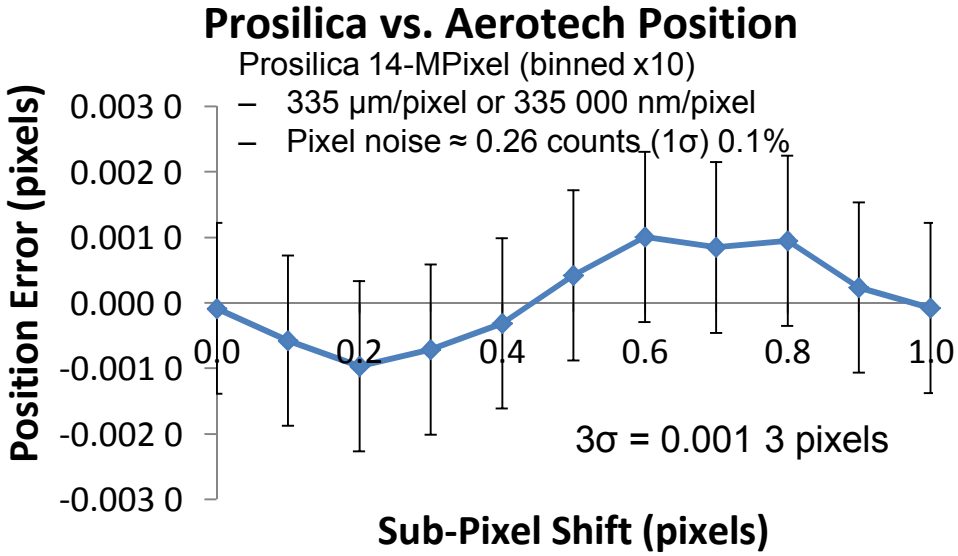


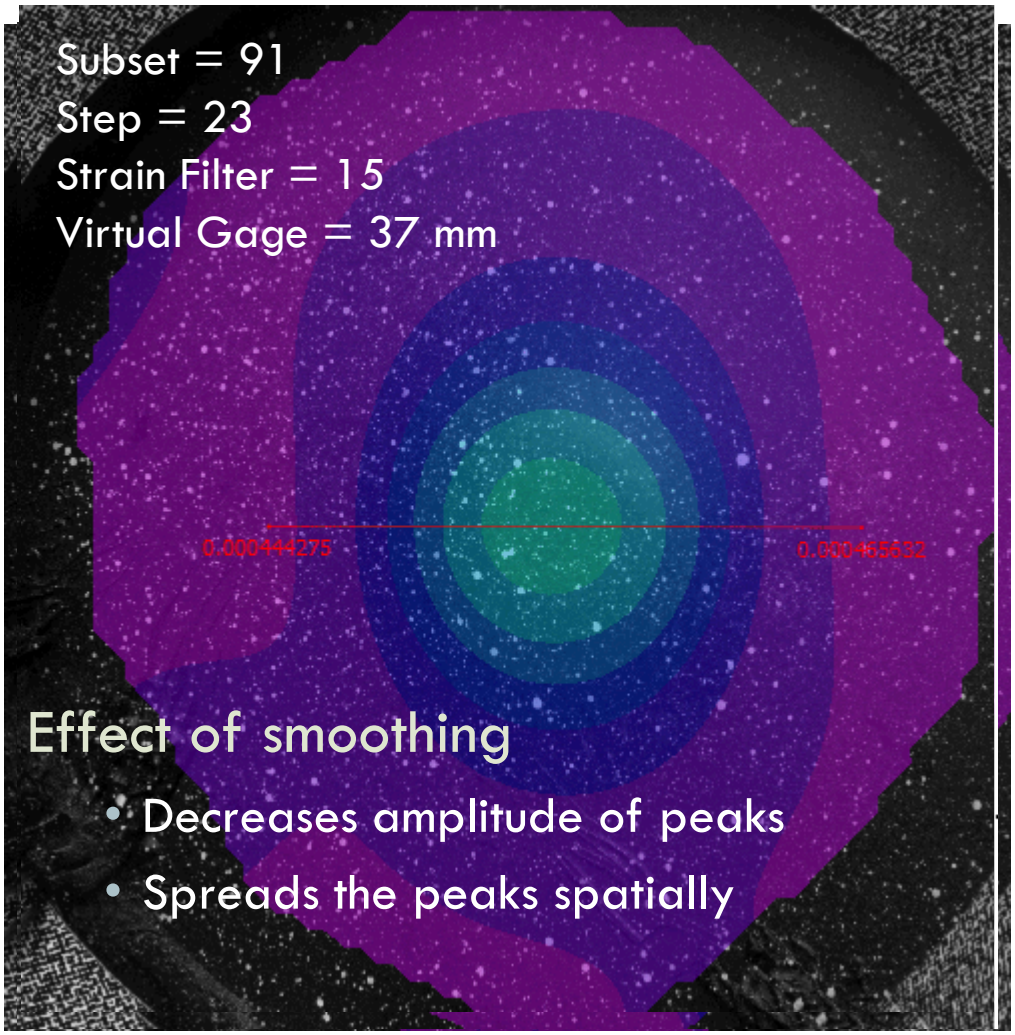


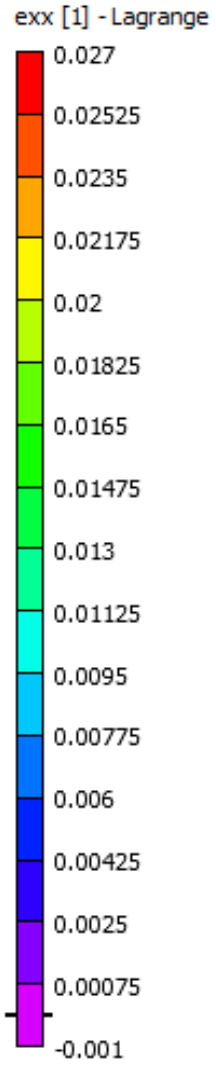
Variance errors dominate bias errors!





Mesh density studies will help determine the non-linear filtering effect of DIC processing.





The penultimate slide: The error table

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2D Error Source	Type	Assessment Method	≈ |pixels|
Lens distortion	B	Either camera calibration (grids) or speckle translation.	Pixels (w/o Calib.)
Camera motion	A,B	Noise Floor or static “dummy” region.	0.5
Sample motion	B	Dummy region or other measurement method	0.5
Turbulence	A,B	Noise floor (must have same environment as test)	0.01 to pixels
Image blur	B	Estimated from synthetic images	0.001
Resolution	B	Estimated via experiments and synthetic images	0.001 (contrast)
Image noise	A	Noise floor	0.01
Speckle contrast	A	Noise floor	0.01
Speckle size	B	Direct measure of speckle size, noise floor, parameter study	0.02 (w/o aliasing)
Aliasing	A,B	Noise floor	0.005
Interpolant	B	Synthetic and experimental image studies for optimum.	0.001 to 0.01
Minimization	B	DIC parameter study, synthetic and exp. image studies	0.005
Shape function	B	DIC parameter study, synthetic and exp. image studies	Linear fit
Subset size	B	DIC parameter study, synthetic and exp. image studies	Noise vs filtering
Filtering	B	DIC parameter study	Spatial resolution
Strain calculation	B	DIC parameter study	Spatial resolution
Coord. system	B	Other means	