SAND2020-9051 TR (slides)
SAND2020-9046 TR (videos)

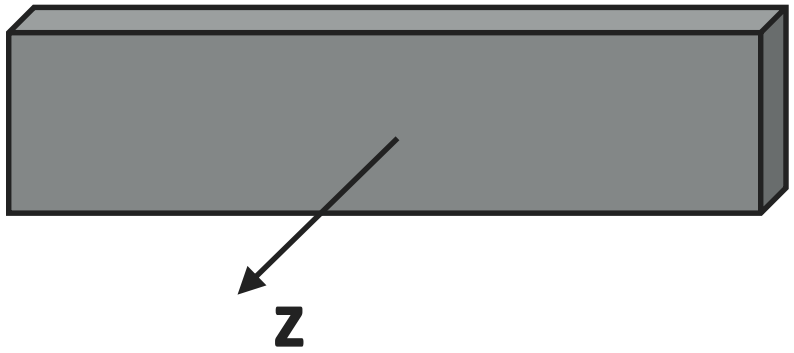
CHAPTER 5: PROCESSING OF DIC IMAGES

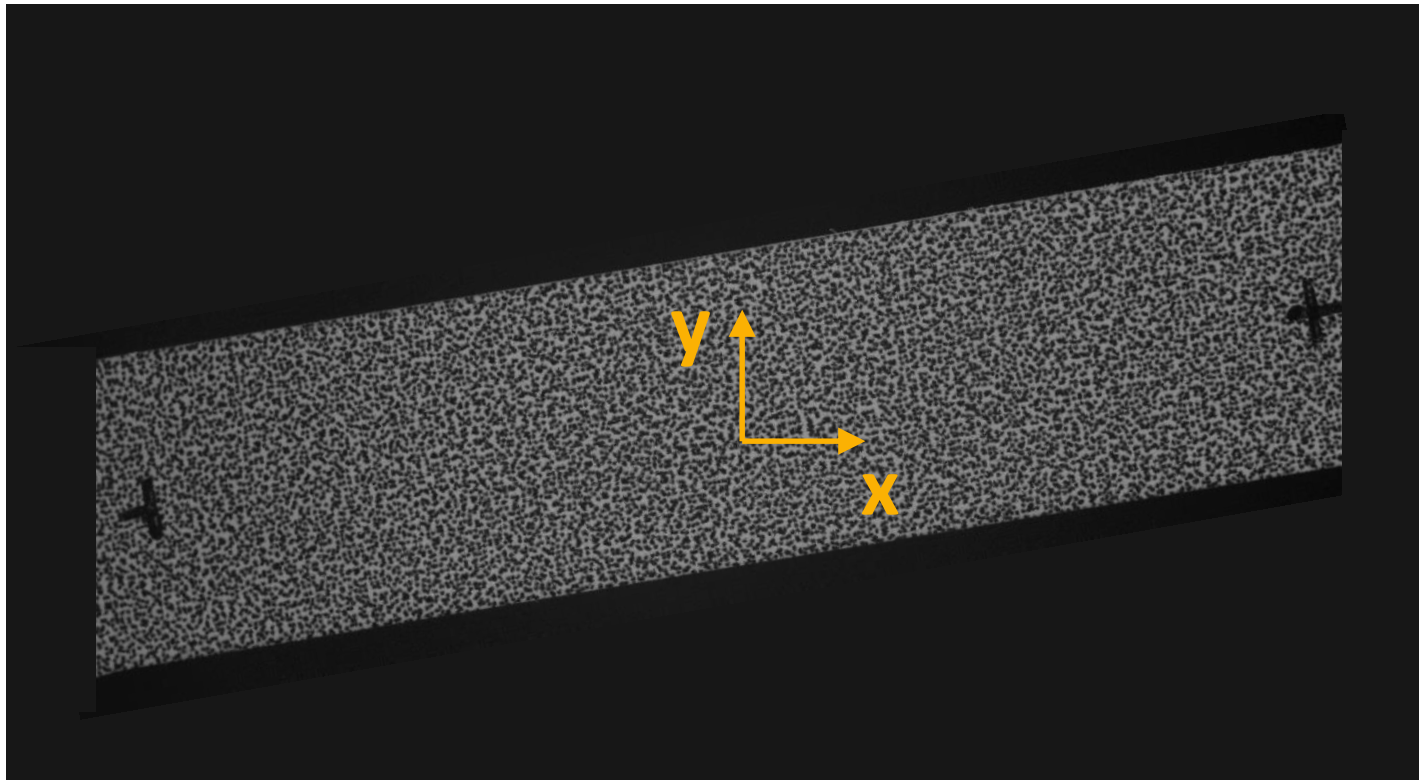
SEC. 5.3: STRAIN CALCULATIONS

SEC. 5.4: UNCERTAINTY QUANTIFICATION

Coordinate system (Not in the Guide!)

- Default coordinate system depends on software
  - Left camera coordinate system
  - Coordinate system centered between cameras
  - Best plane fit
- Best plane fit
  - Sets z-axis perpendicular to ROI (good for planar specimens)
  - In-plane axes aligned with image

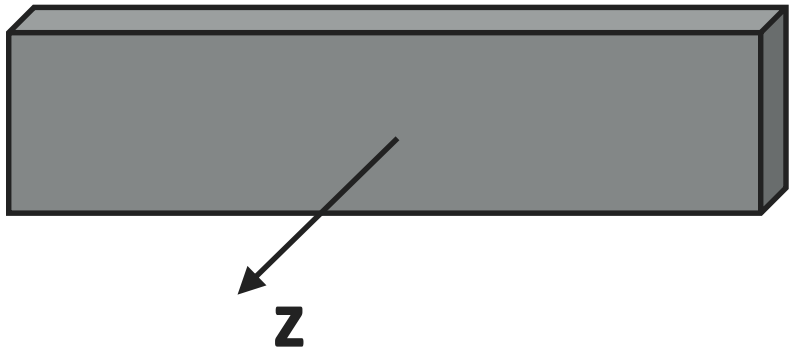


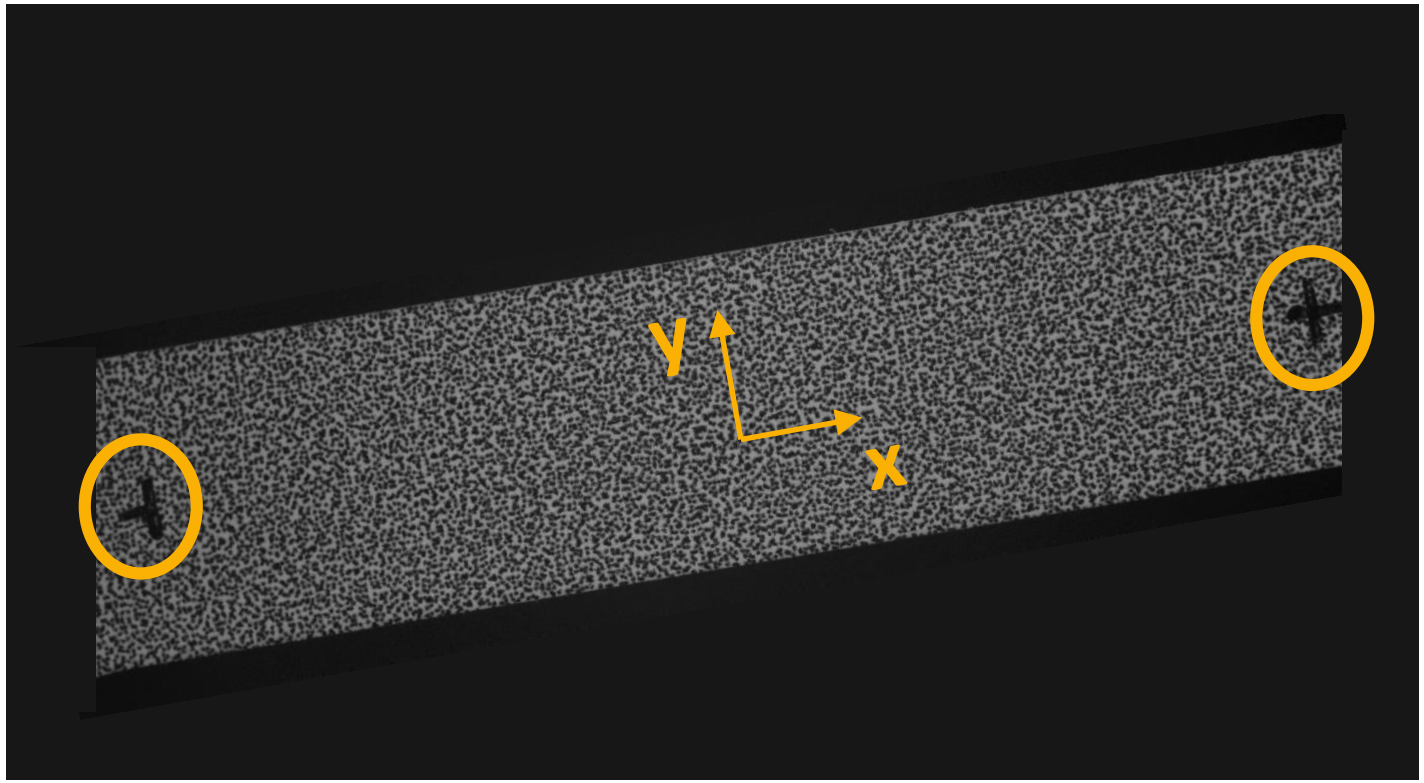


Coordinate system (Not in the Guide!)

- Best plane fit
  - Sets z-axis perpendicular to ROI (good for planar specimens)
  - In-plane axes aligned with image

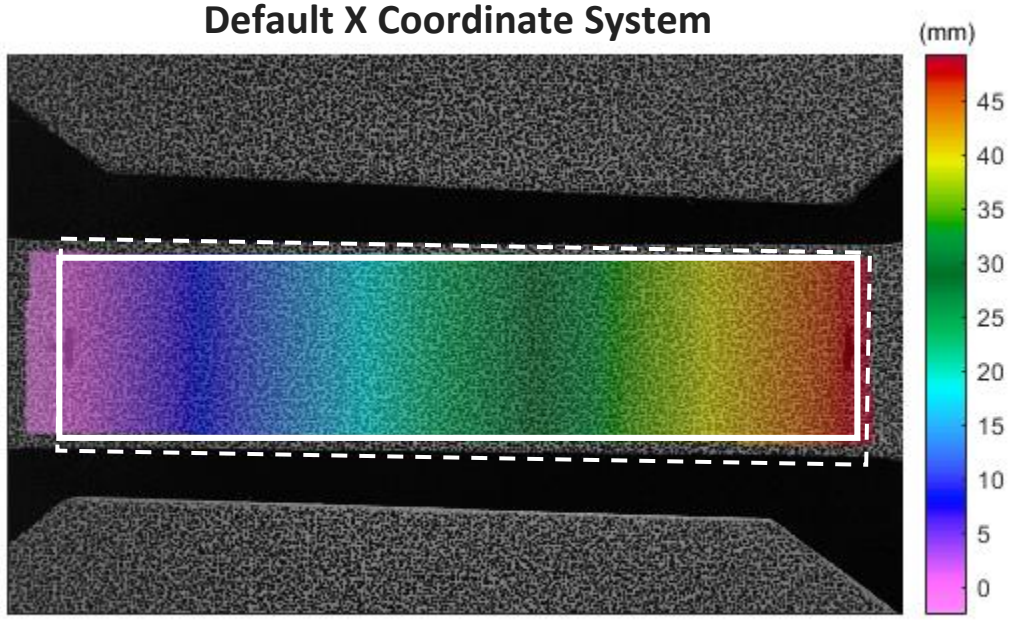
- Coordinate transform is often required to align axes with something meaningful, like test piece axis or direction of pull
- Fiducial marks placed on specimen during patterning can help when selecting a coordinate system



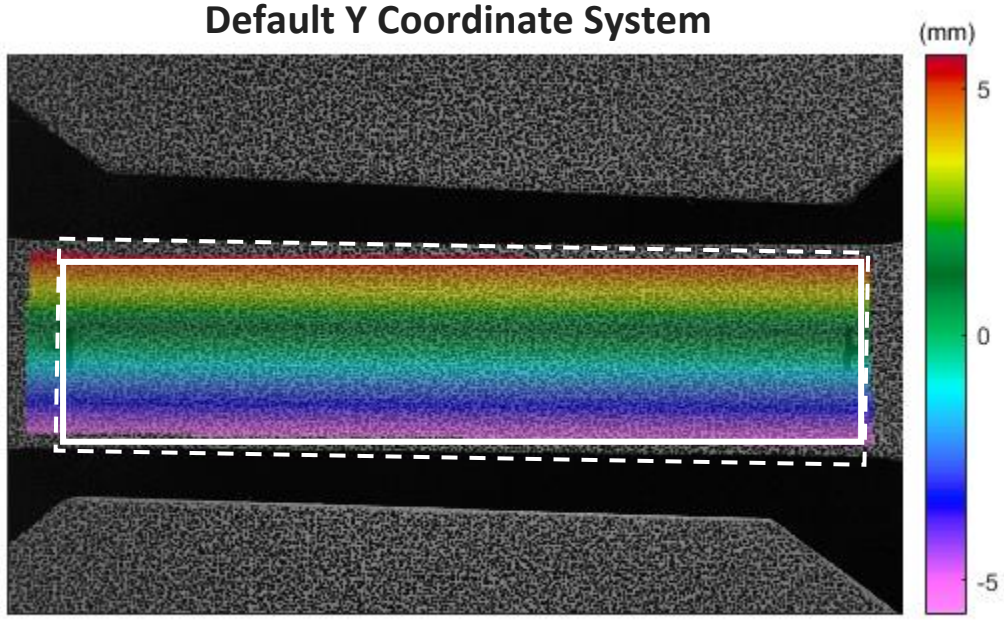


Coordinate system (Not in the Guide!)

Default X Coordinate System



Default Y Coordinate System



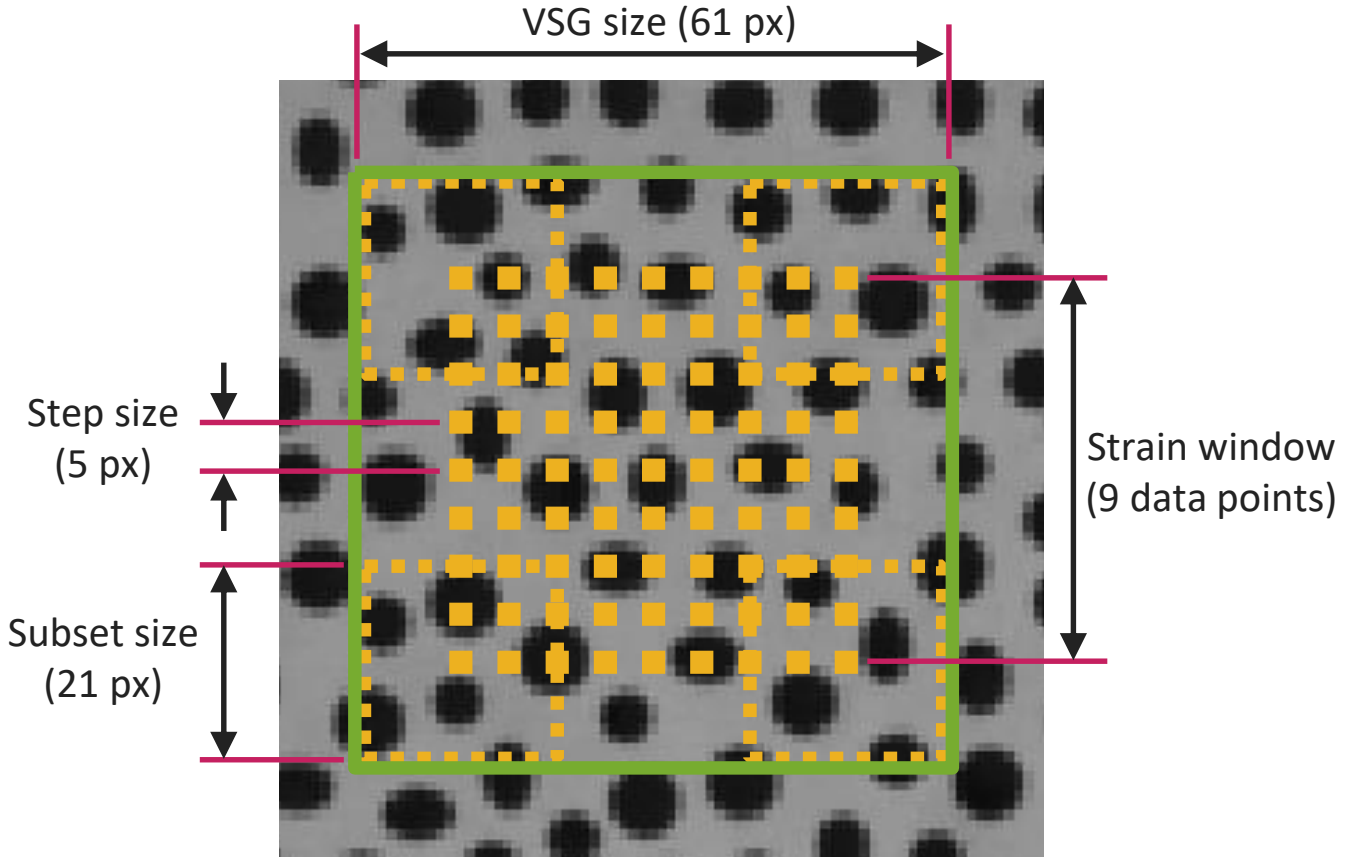
Misalignment might be subtle, but aligning system will improve consistency between results

Virtual Strain Gage (VSG) and Examples of Strain Gage Calculation Methods Sec. 5.3.1 and Sec. 5.3.2

VSG size:

- Local region of the image that is used for strain calculation at a given location
- Analogous to, but not exactly, the size of a physical strain gage

$$L_{VSG} = (L_{window} - 1)L_{step} + L_{subset}$$



Strain computation methods:

- Many methods, such as:
  - Subset Shape Function
  - Finite Element Shape Function
  - Strain Shape Function
  - Spline Fit
- See software manual for details

Uncertainty Quantification (UQ)
Sec. 5.4

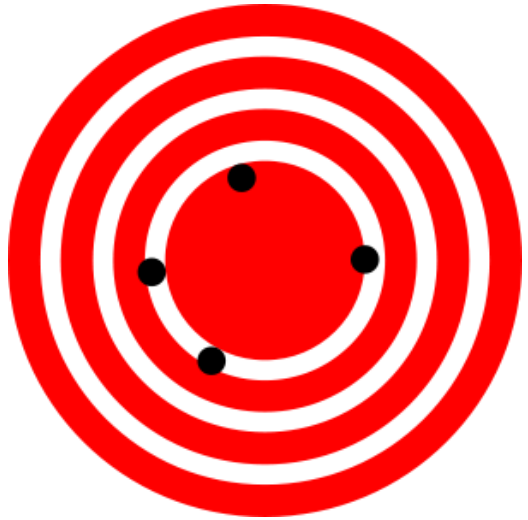
A comprehensive discussion is outside the scope of this course; here, we will only highlight topics in the GPG

- Two types of error:

1. Variance (noise): random errors centered about the true value
   - e.g. from camera noise
   - Quantified using a noise-floor analysis

2. Bias: Offset of the mean from the true value
   - e.g. from lens distortions, interpolant choice, out-of-plane motion in 2D-DIC, insufficient spatial resolution
   - Can be interrogated using rigid translation, comparison to a known solution, VSG convergence, and others

- Note! There is often a trade-off between noise and bias due to over-smoothing of the data when choosing user defined parameters



Noisy

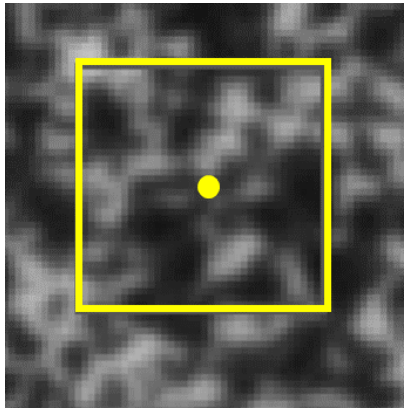
Biased

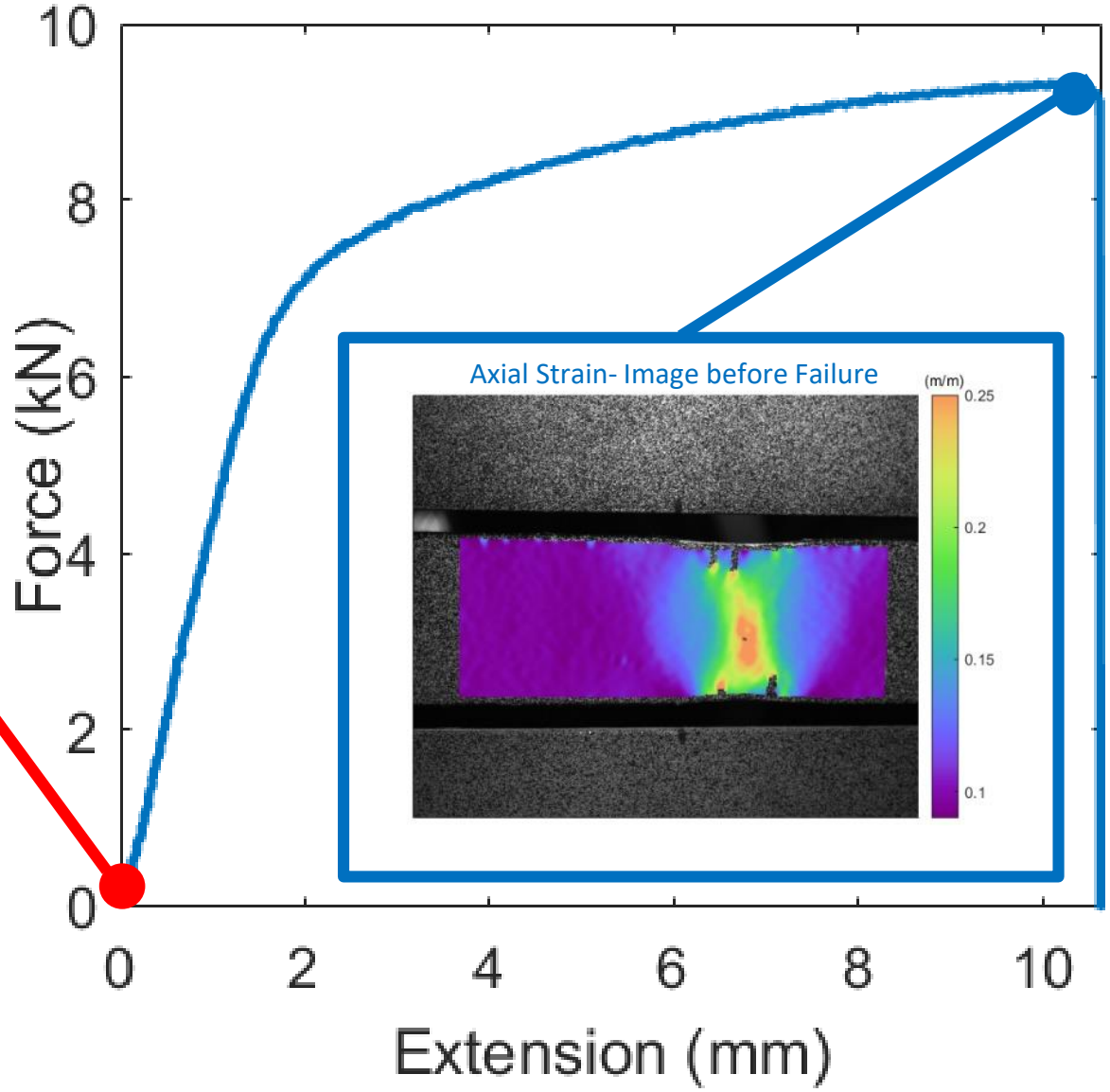
Virtual Strain Gage Study Example using Stereo-DIC Challenge Images: StereoSample5-Tension

Reference Image: Zero force

1. Select subset size and step size based on previously discussed metrics

Subset: 37 px
Step: 7 px
Pre-filtering: Yes





iDICs

Virtual Strain Gage Study Example
Sec 5.3.1

2. Select two images to correlate against reference image:
   a) an image after the reference image but zero force,
   b) the image of the highest strain *gradient*.

3. Analyze these images with different DIC settings, varying the VSG size
   - Tip 5.4: The dominant (but not only) variables that affect VSG size are subset size, step size, strain window/filter window, and strain shape function

4. Extract a line cut through the region of highest strain gradient. Plot the strain for each of the image analyzes.
   - Caution 5.3: Ensure that the line cut does not bridge a crack!

Static Image

noise

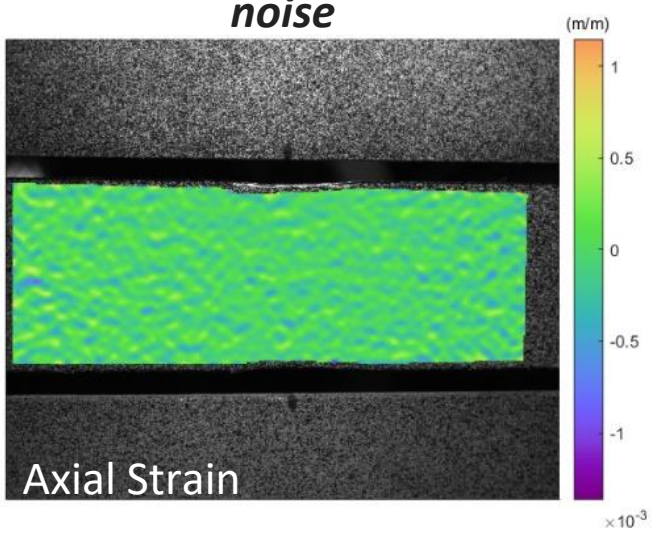
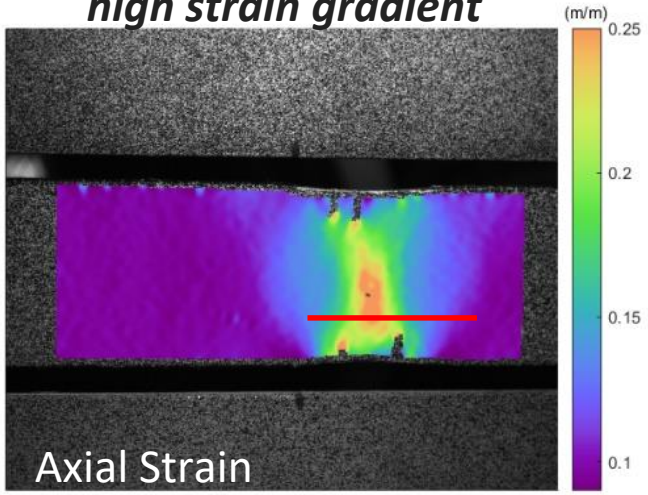
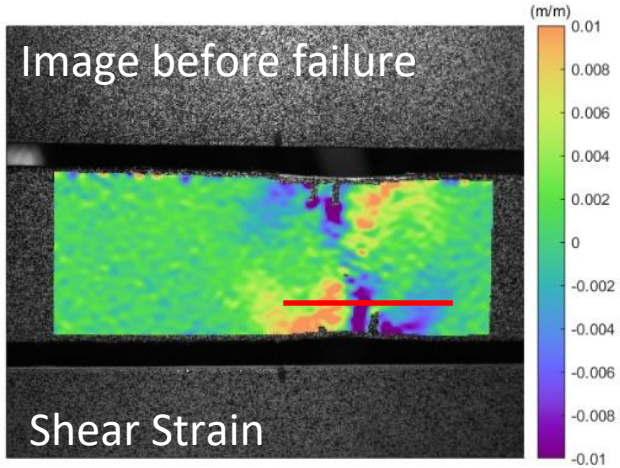
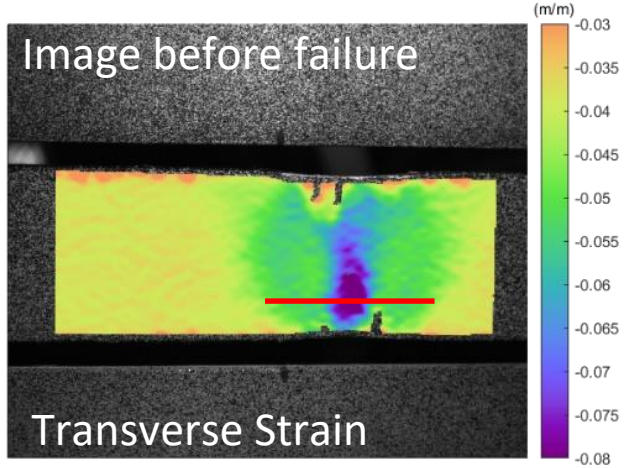


Image before Failure

high strain gradient

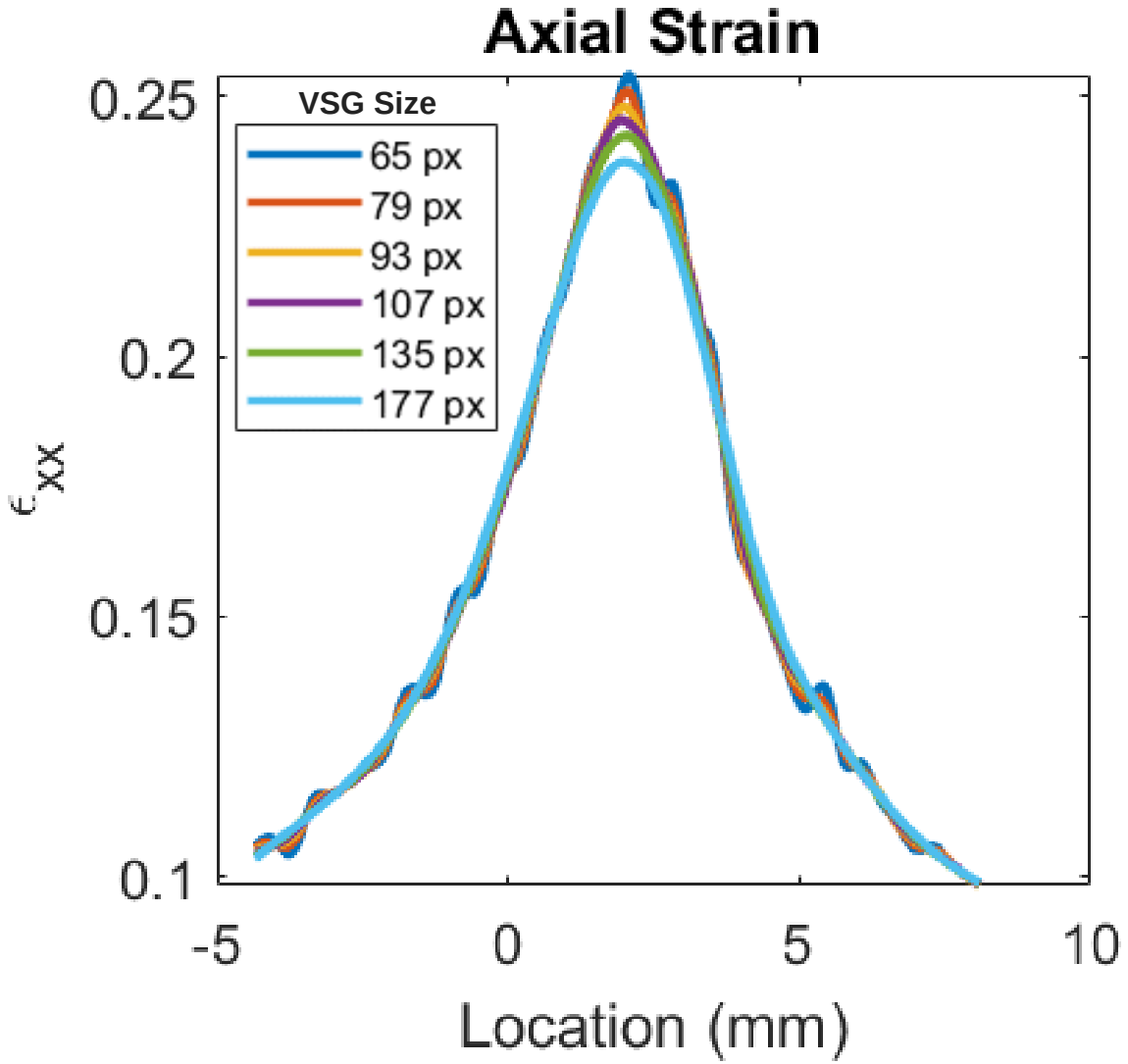


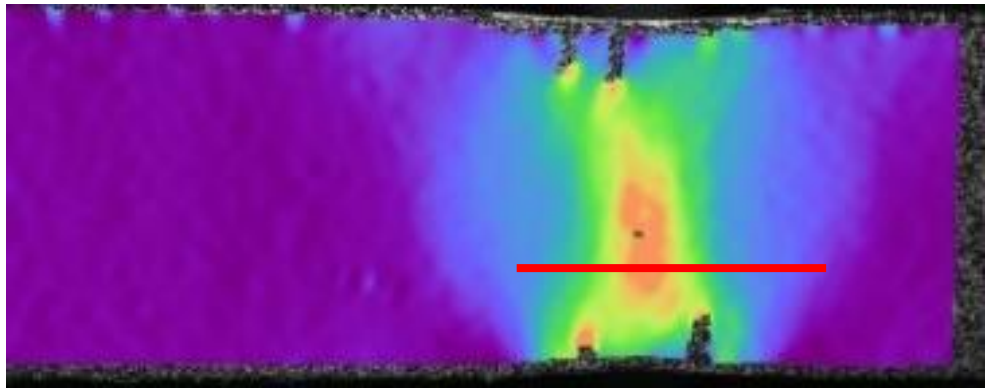




Virtual Strain Gage Study Example
Sec 5.3.1

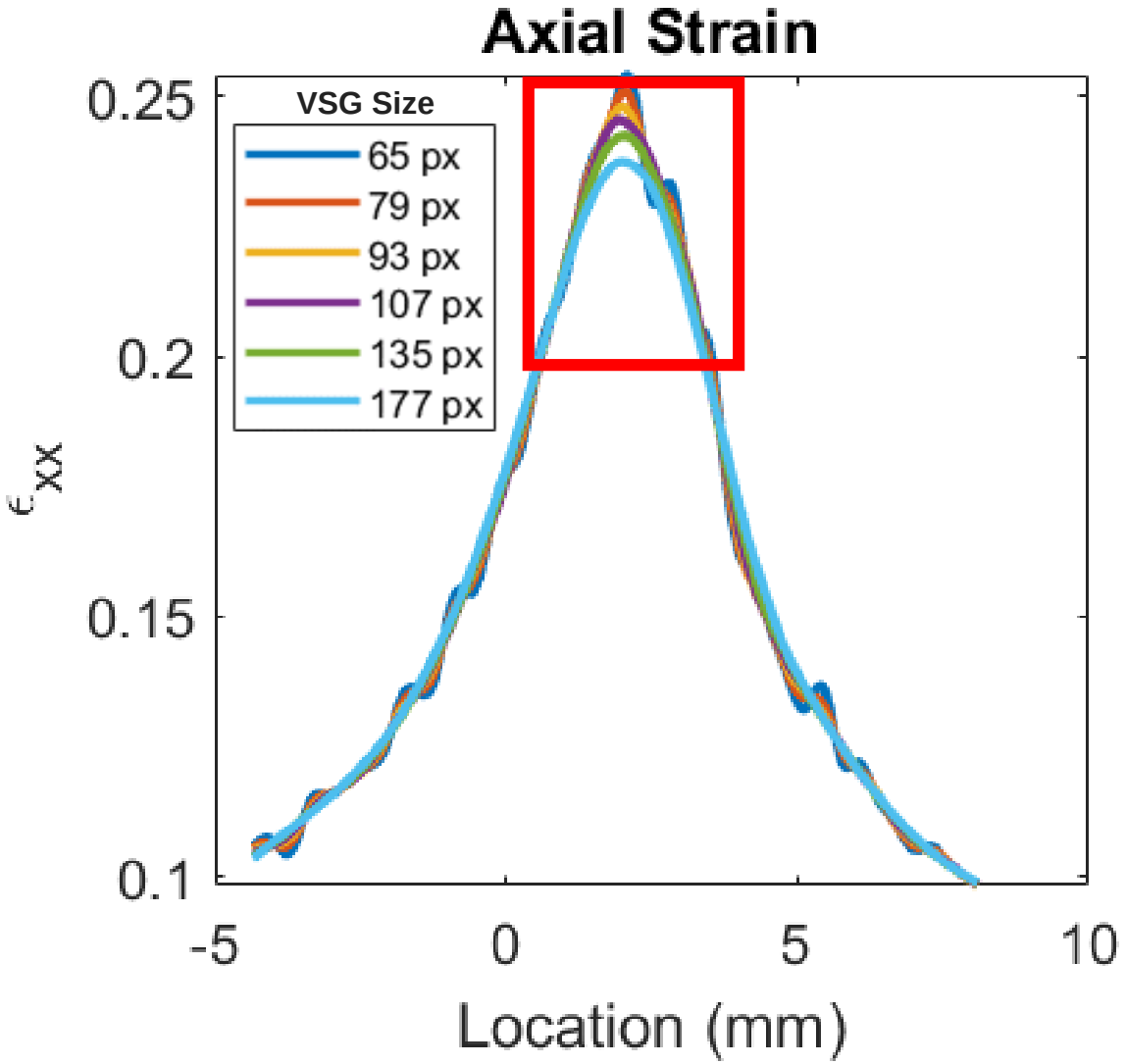
5. Assess convergence.

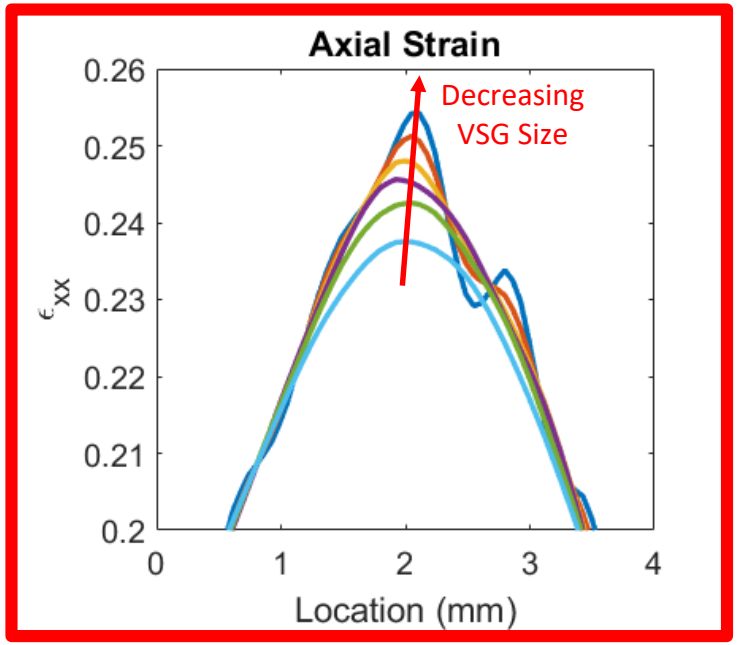




Virtual Strain Gage Study Example
Sec 5.3.1

5. Assess convergence.





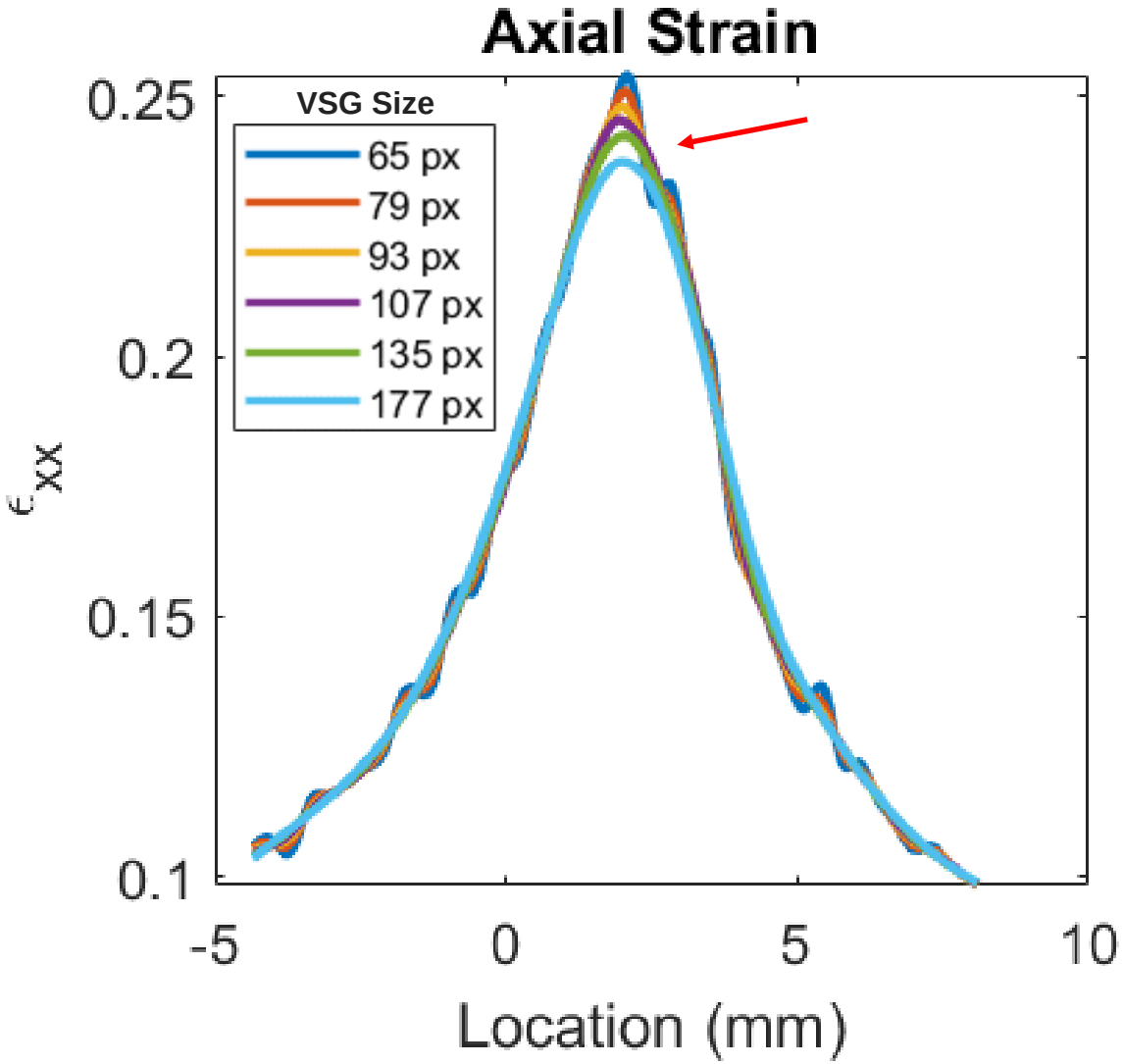
- If the maximum strain amplitude converges with smaller VSG, then the actual maximum strain amplitude has been captured.

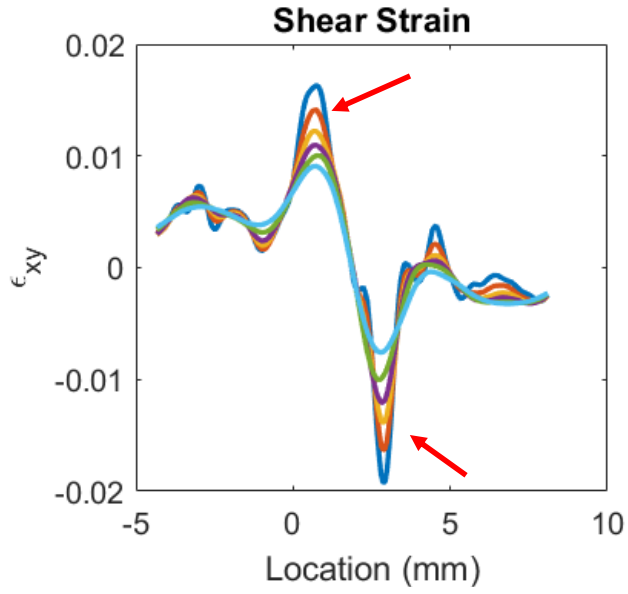
- If the maximum strain amplitude never converges, the true value can not be known, but is instead equal to or greater than the reported strain measurements.

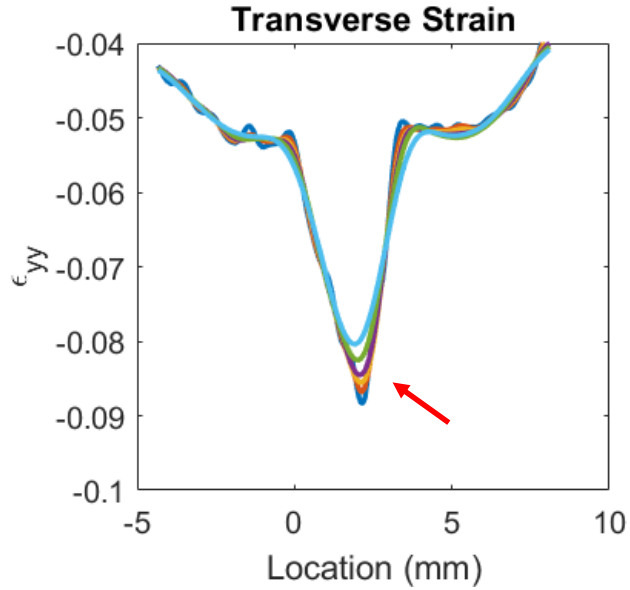
- *Tip 5.5: If strains do not converge, test can be repeated with smaller FOV/ higher magnification*

Virtual Strain Gage Study Example
Sec 5.3.1

5. Assess convergence.



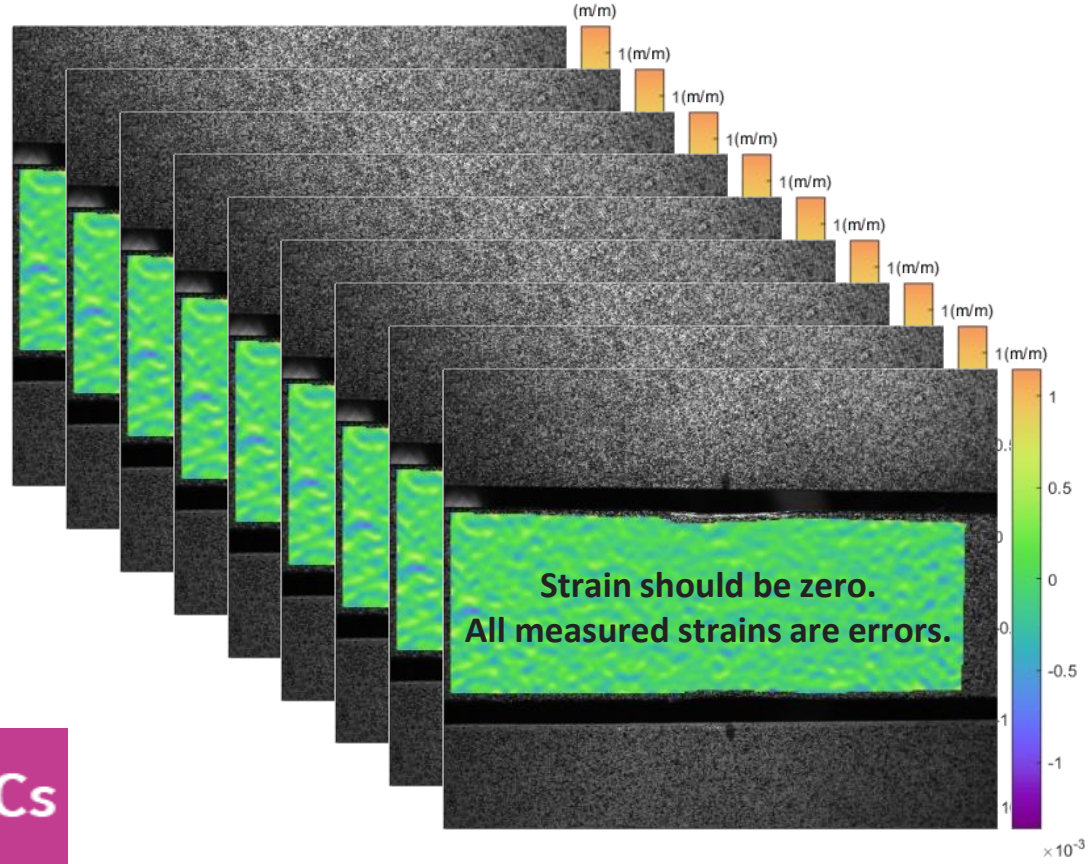




- *Tip 5.5: If strains do not converge, test can be repeated with smaller FOV/ higher magnification*

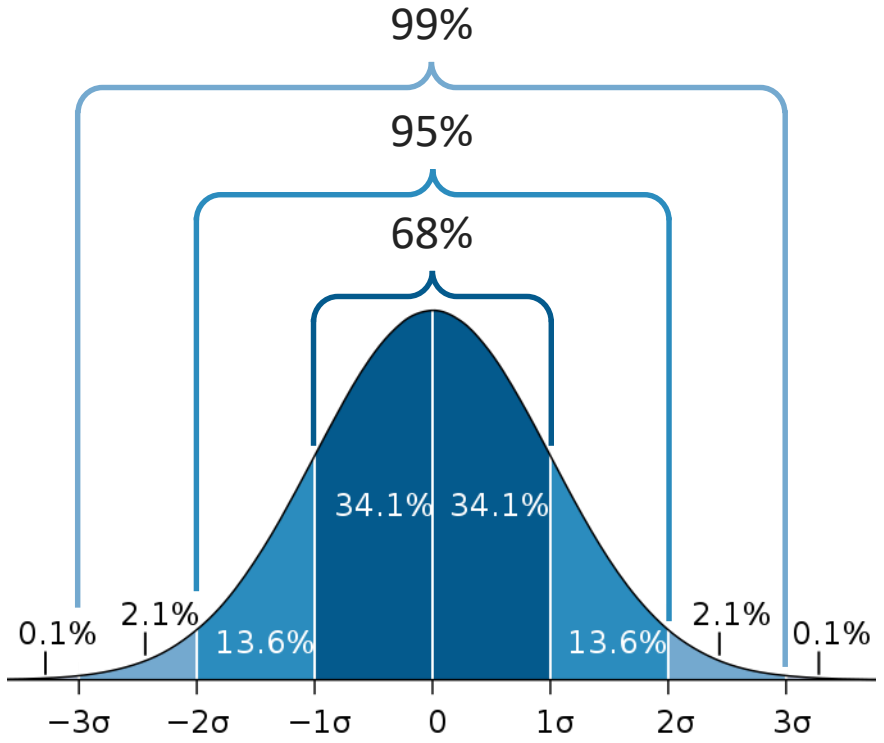
Virtual Strain Gage Study Example
Sec 5.3.1

6. Quantify the noise
   a) Series of static images
      - Evaluates camera noise, but not calibration parameters
      - Lower bound of noise floor
   b) Series of rigid-body motion images
      - More thorough evaluation of noise floor



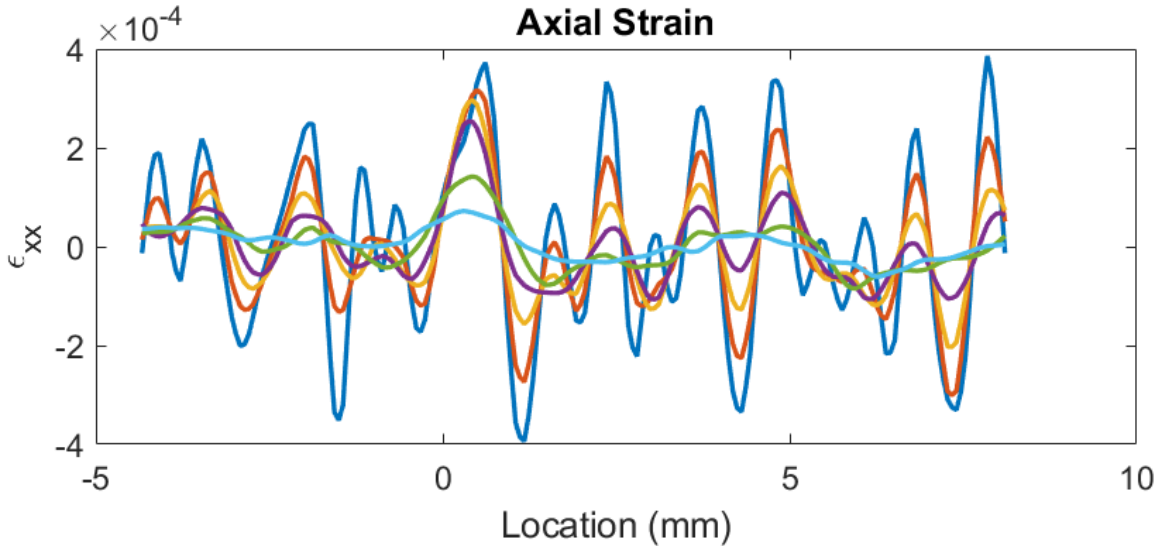
- Noise Floor = α*(standard deviation)
  - Spatial stdev → variance of QoI across ROI
  - Temporal stdev → variance of QoI over time
  - Combine all points in ROI and all images in time

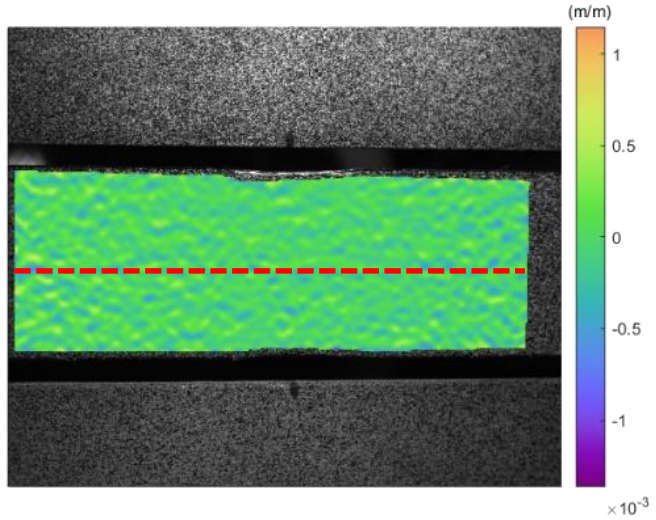
- 3-sigma rule
  - α = 1 → Less conservative
  - α = 3 → More conservative

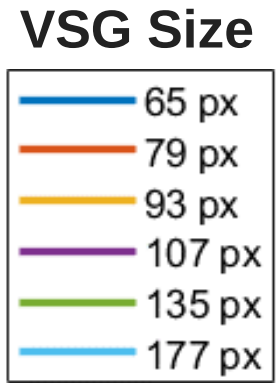


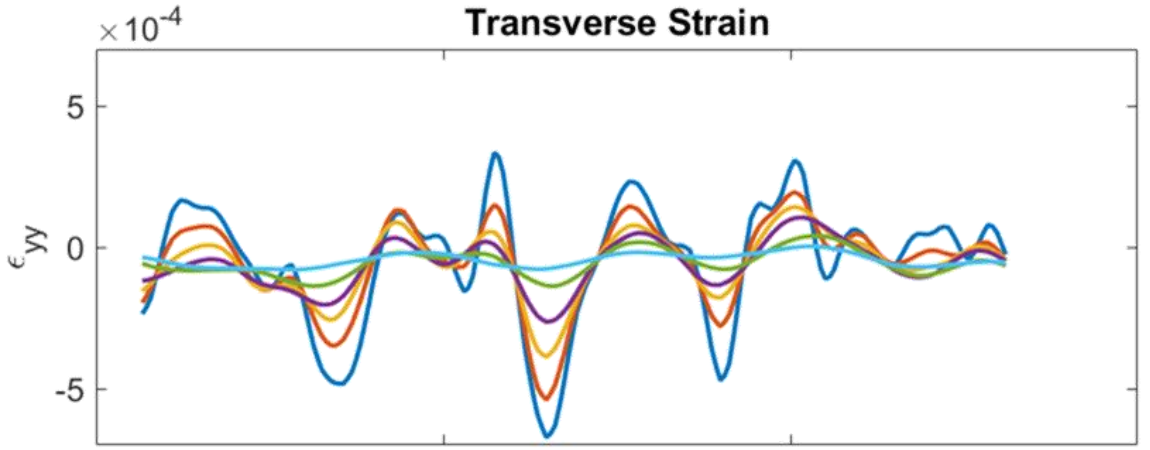
Virtual Strain Gage Study Example
Sec 5.3.1

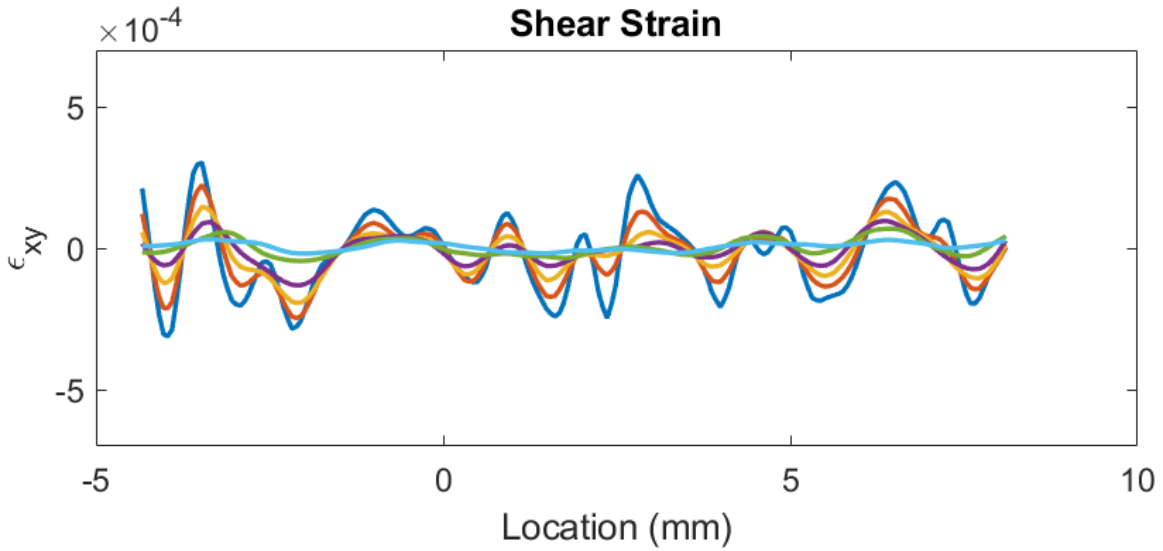
6. Quantify the noise







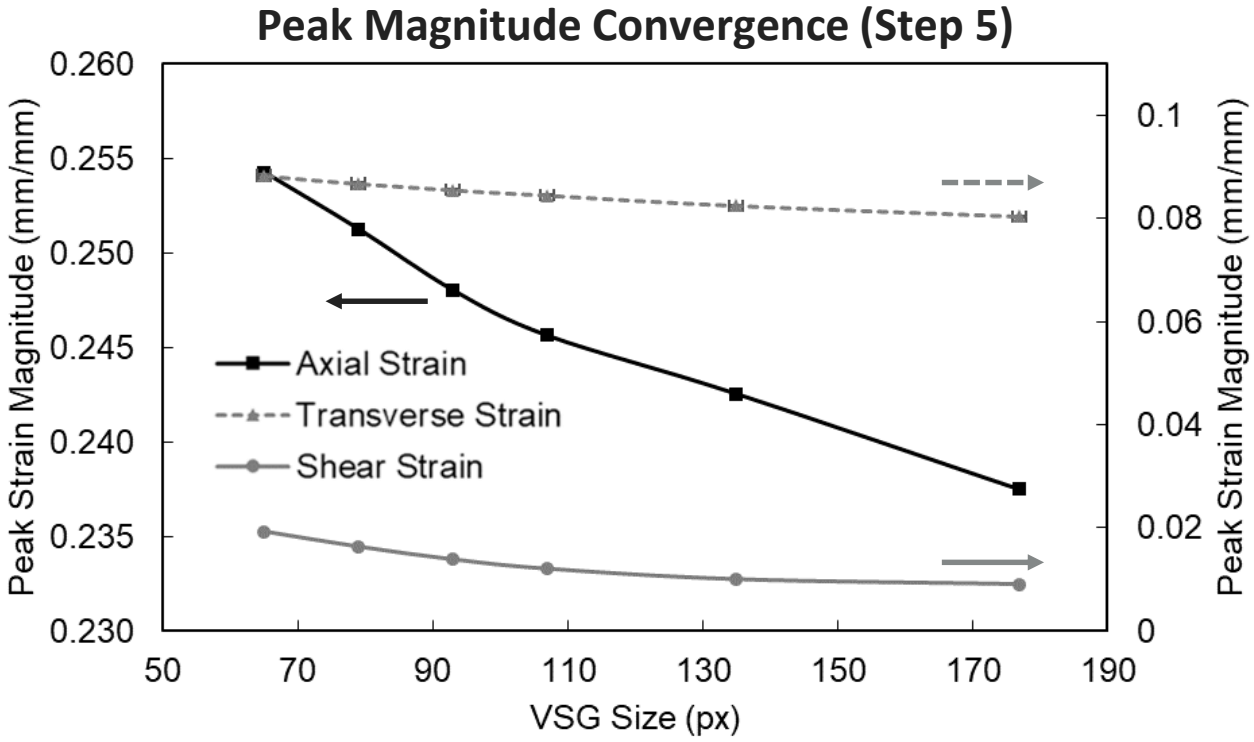


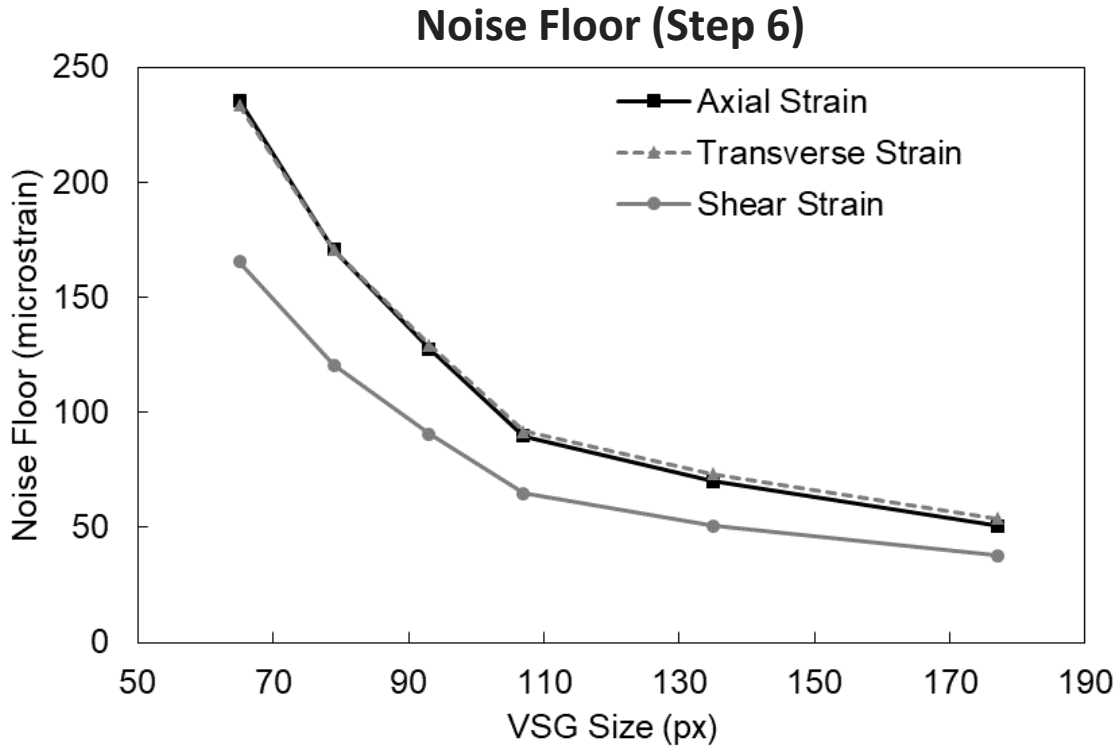


iDICs

Virtual Strain Gage Study Example
Sec 5.3.1

7. Ultimately, the right parameters are a function of the accuracy to noise ratio for a given QOI and are application dependent and a matter of expert judgement.

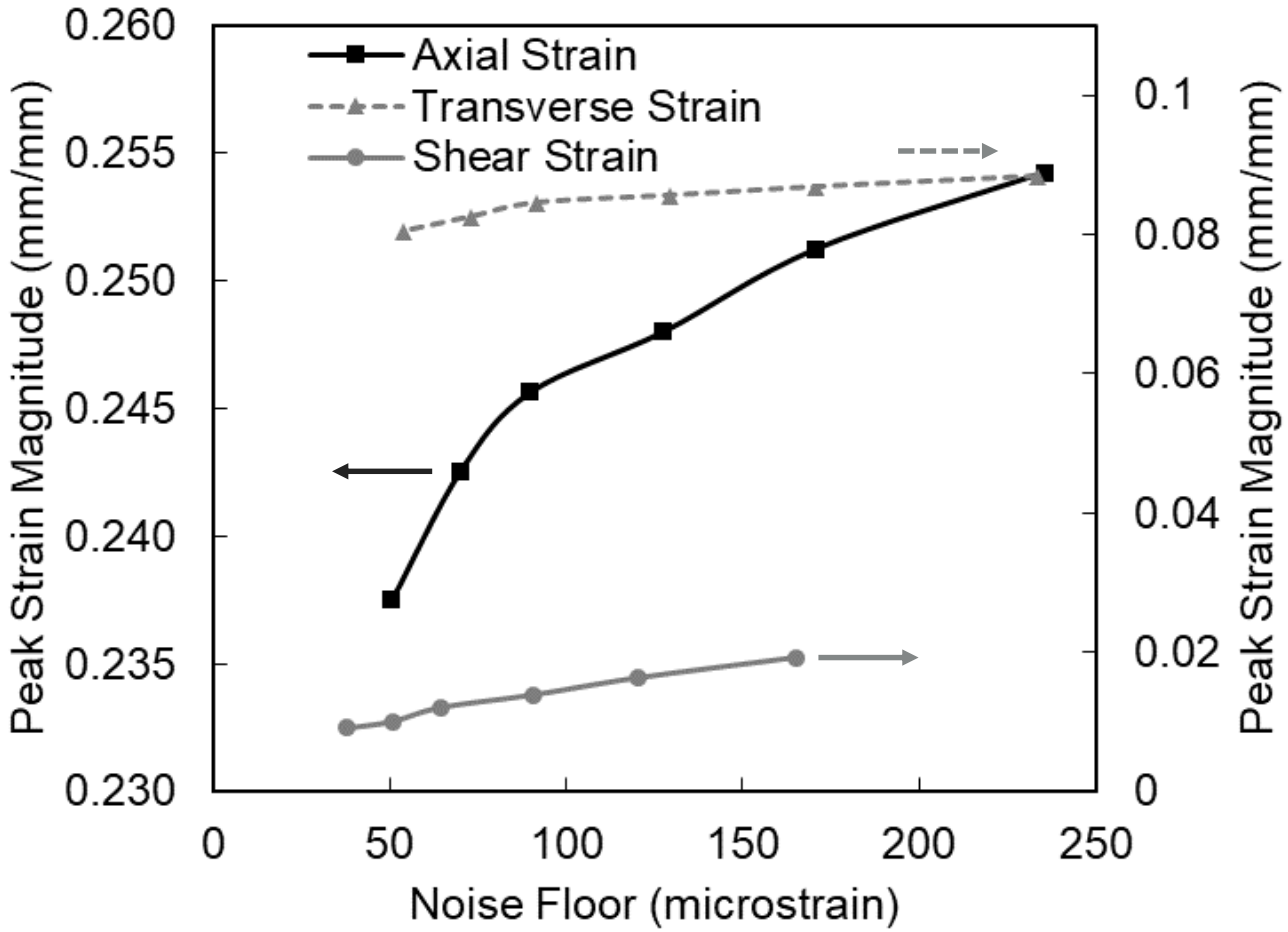




Virtual Strain Gage Study Example
Sec 5.3.1

7. Ultimately, the right parameters are a function of the accuracy to noise ratio for a given QOI and are application dependent and a matter of expert judgement.

Bias Errors



Variance Errors

CHAPTER 6: REPORTING REQUIREMENTS

Reporting Requirements

- Necessary for others to understand your measurements and repeat your measurements
- Build credibility for your experimental procedures and analysis

Table 1. DIC Hardware Parameters

Camera	<Manufacturer and Model>
Image Resolution	2448 x 2048 pixels^2
Lens	<Manufacturer and Mode, and Focal Length>
Aperture	f/8
Field-of-View	100 mm
Image Scale	24.5 pixels/mm
Stereo-Angle	25 degrees
Stand-off Distance	240 mm
Image Acquistion Rate	15 Hz
Patterning Technique*	Base coat of white spray paint with black ink stamped speckles
Pattern Feature Size (approximate)	5 pixels / 0.2 mm

*A more complete description of the patterning technique may be appropriate in the main text.

Reporting Requirements

Table 2. DIC Analysis Parameters

DIC Software	<Manufacturer, Version number>
Image Filtering	Gaussian filter with a 3x3 pixel kernel
Subset Size	21 pixels / 0.86 mm
Step Size	7 pixels / 0.29 mm
Subset Shape Function	Affine
Matching Criterion	Zero-normalized sum of square differences (ZNSSD)
Interpolant	Bi-cubic spline
Strain Window	15 data points
Virtual Strain Gauge Size*	119 pixels / 4.9 mm
Strain Formulation	Green-Lagrange
Post-Filtering of Strains**	Median temporal filter, span of 5 data points / 0.33 seconds
Displacement Noise-Floor***	0.01 pixels / 0.4 µm (in-plane); 0.03 pixels / 1.2 µm (out-of-plane)
Strain Noise-Floor***	250 µm/m

*The VSG size is computed from Eqn. 7.2 in the DIC Good Practices Guide [1]. Other estimations of the VSG size may be more appropriate, depending on the strain calculation method used in the DIC software.
**A more complete description of any pre- or post-filtering may be appropriate in the main text.
***A brief description of how the noise-floor was computed should be included in the main text.

Summary

- DIC is an extremely powerful tool that can be used to capture shapes, displacements, strains, and others
- The guidelines presented in this course are for a well-controlled environment; more complicated setups/ tests may require compromises
- Garbage in – garbage out! DIC requires careful attention to setup, test operation, and data processing
- Reporting of DIC parameters gives us credibility as a community
- Join a working group to help us improve DIC practices and guidelines. All experience levels welcome!

guide@idics.org

SAND2020-9051 TR (slides)
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END MATTER

Image credit

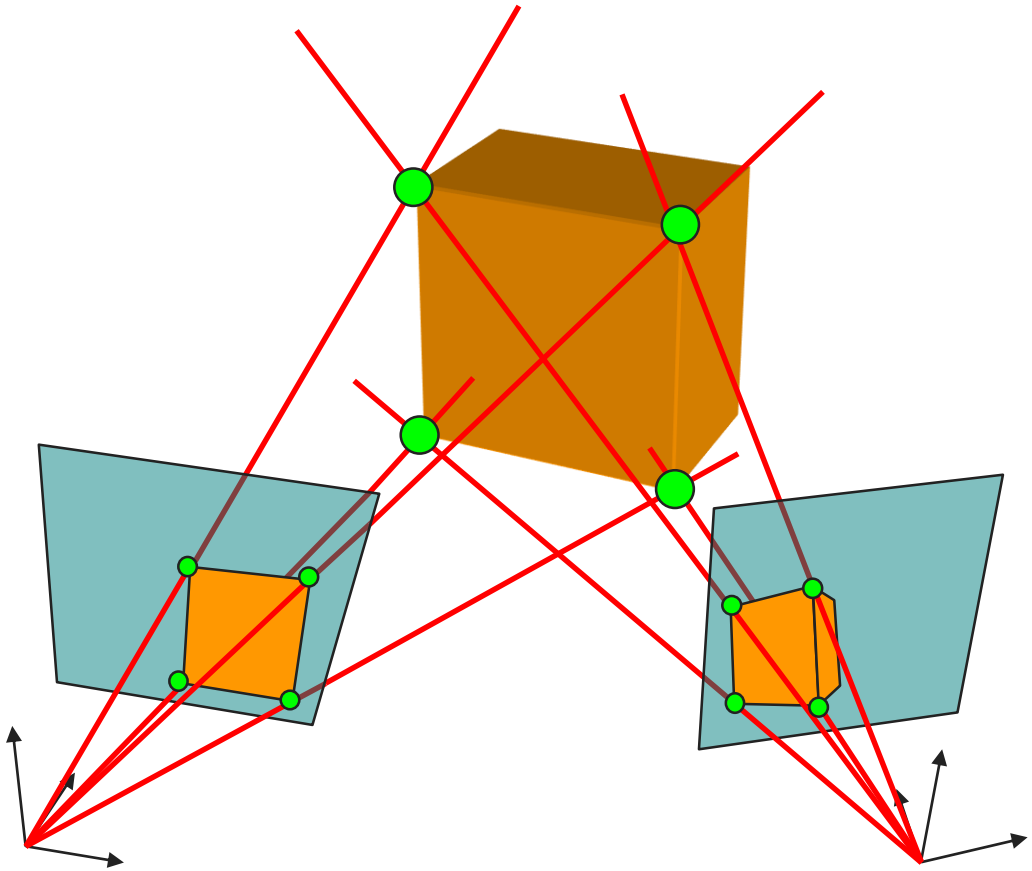

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Image credit

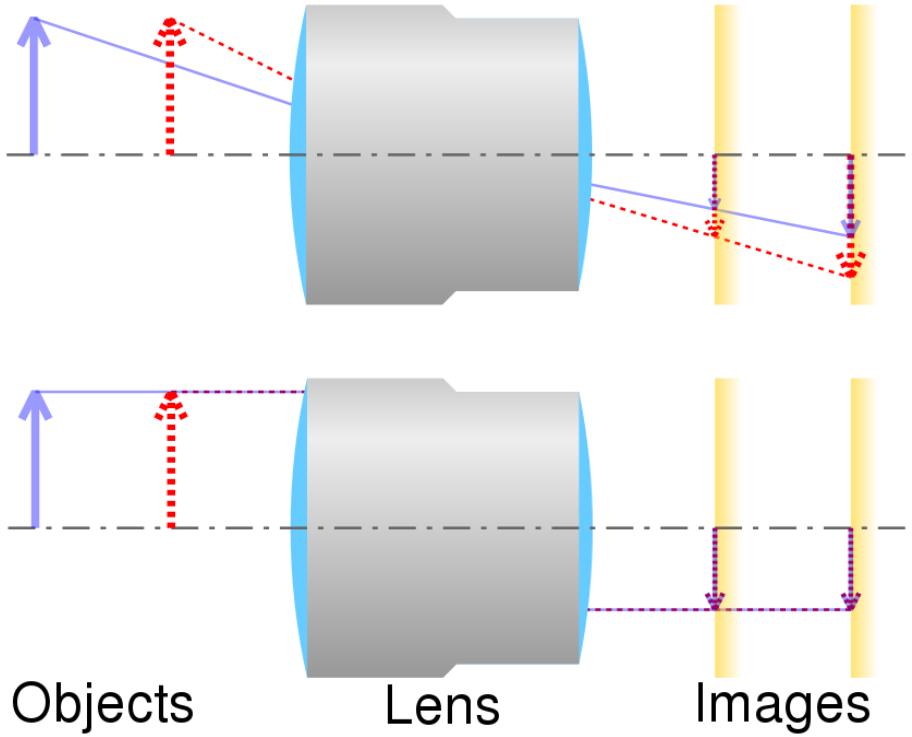

Image credit Cmglee.
Original image available at
https://commons.wikimedia.org/wiki/File:Comparison_of_telecentric_lenses.svg
(Current version shows 2/4 subfigures found in the original.)

Image credit Koyaanis Qatsi.
Images available at https://en.wikipedia.org/wiki/Focal_length

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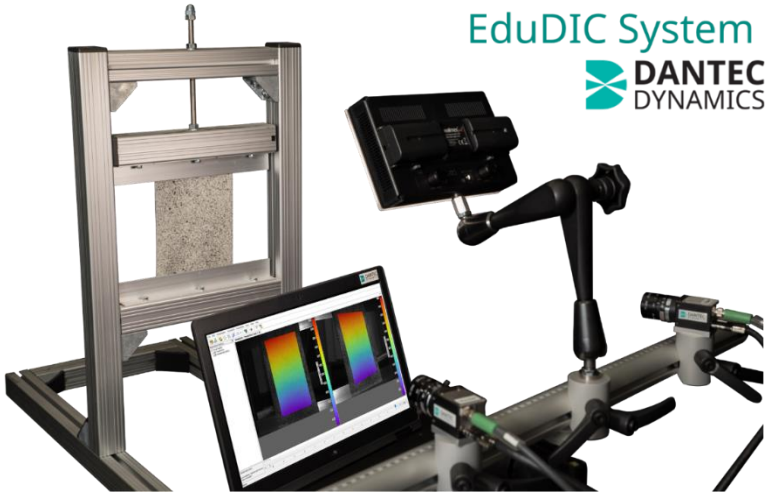

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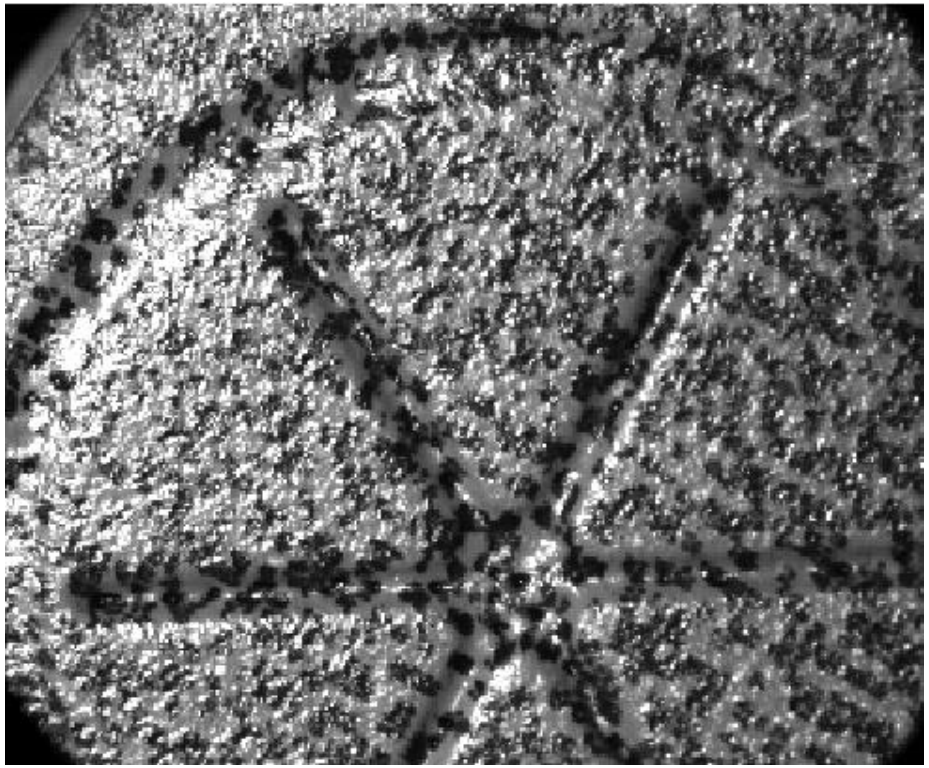
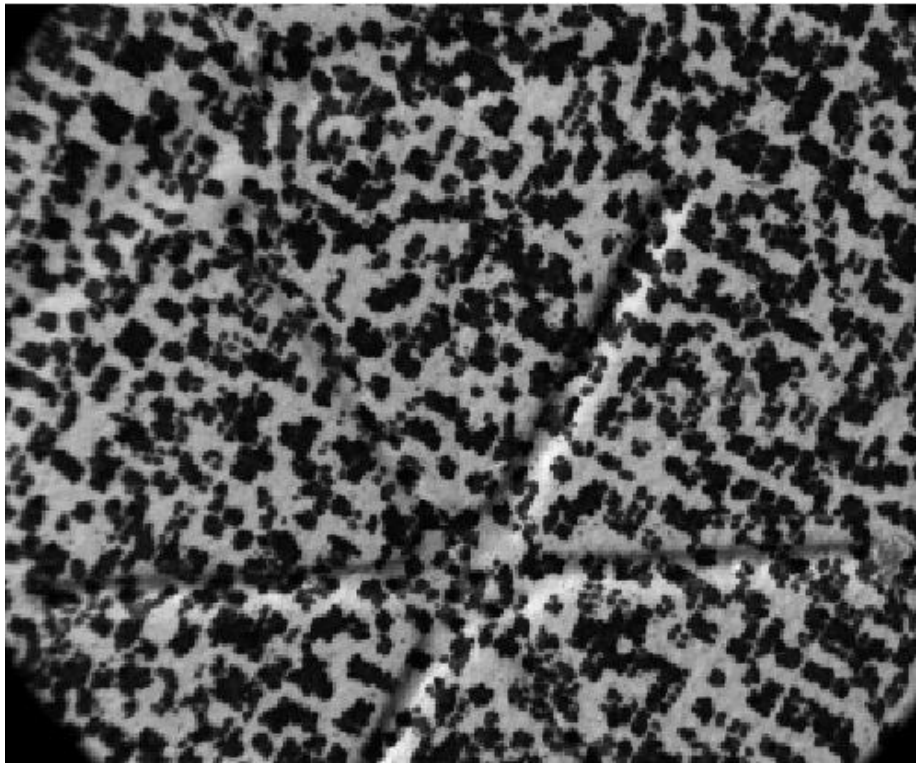
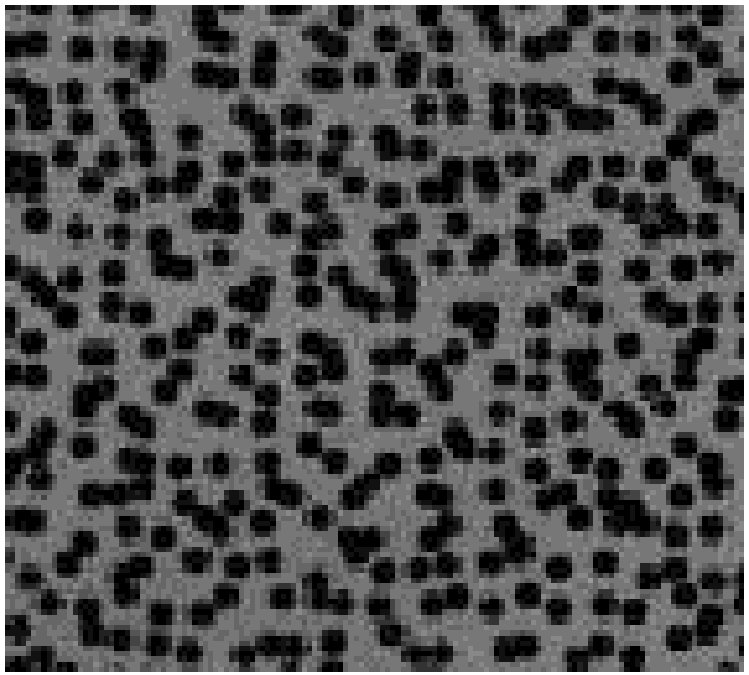
Image credit

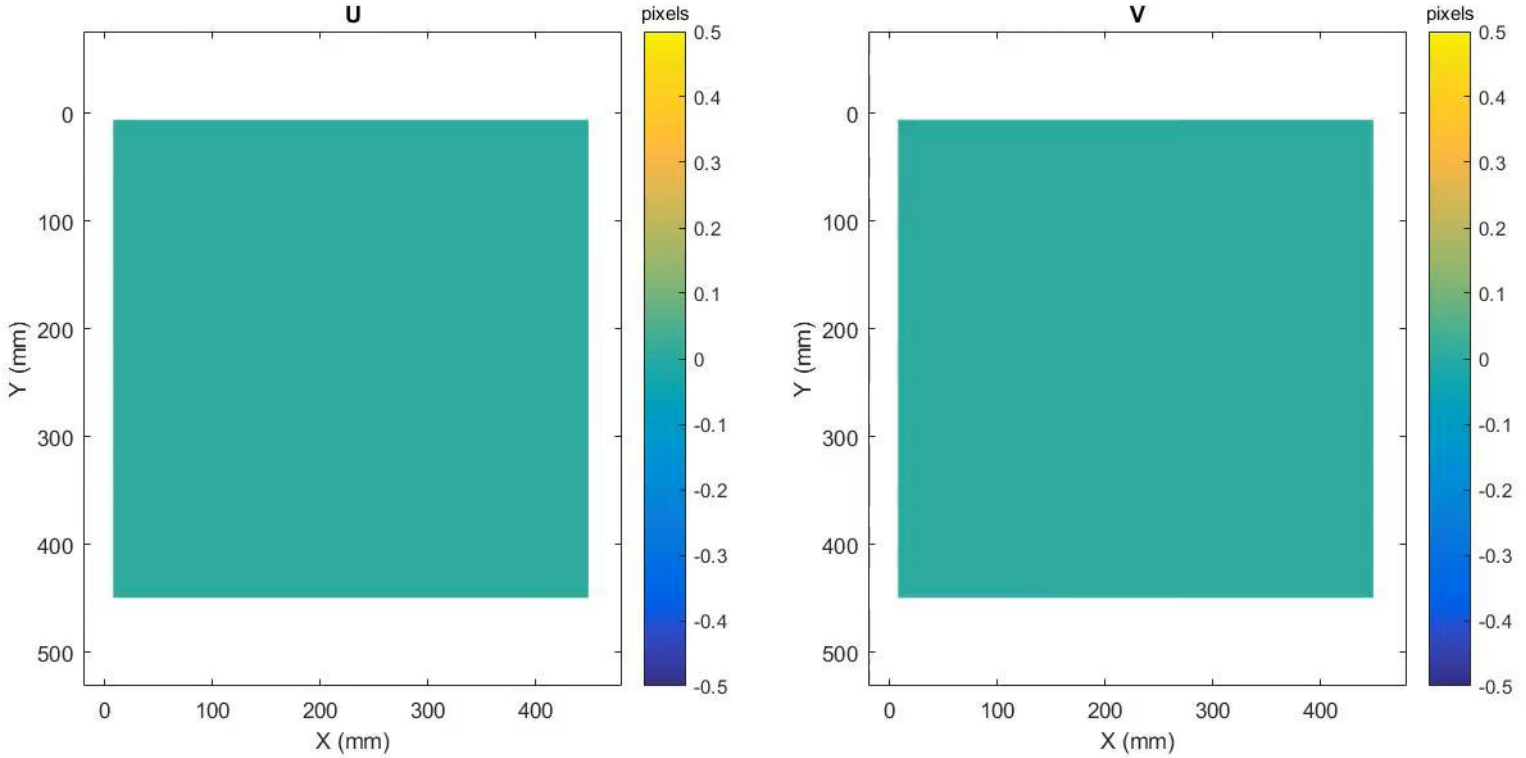




Cooper, M. A., et al. (2016). Advancement of Optical Methods in Experimental Mechanics, Volume 3, Springer: 19-26.

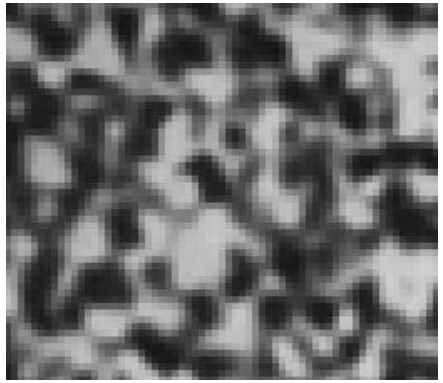
Image credit

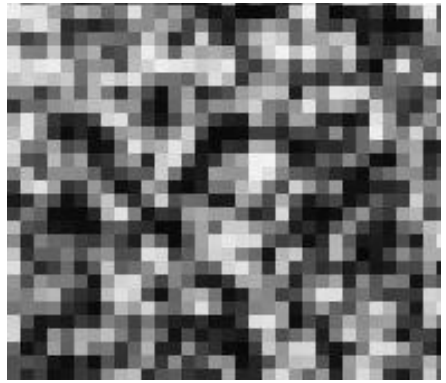




EMC Jones (2018) *Exp. Mech.* 58:1133-1156

Image credit





DIC Challenge Sample 6, www.sem.org/dicchallenge
P. Reu (2011) *Exp. Mech.* 51(4):443-452

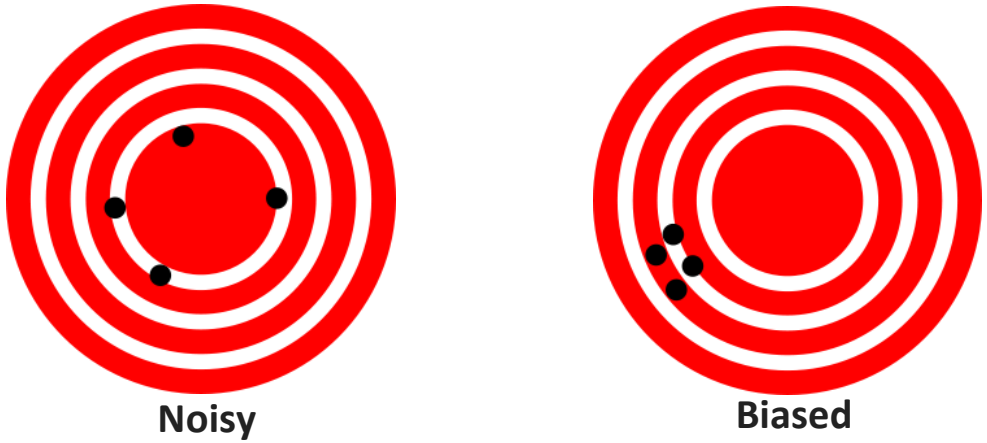
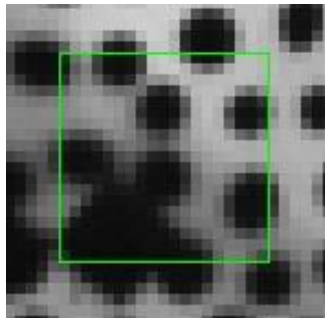
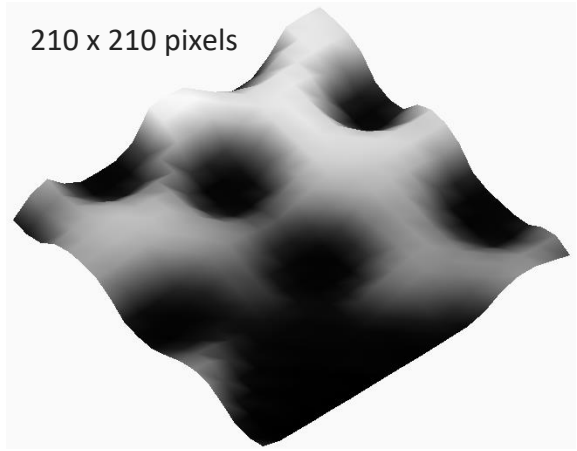
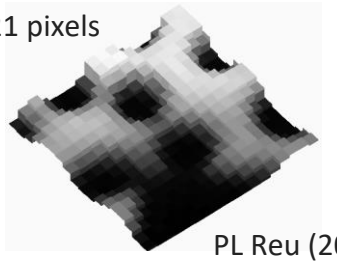


Image credit: DarkEvil. Images available at:
https://en.wikipedia.org/wiki/Accuracy_and_precision







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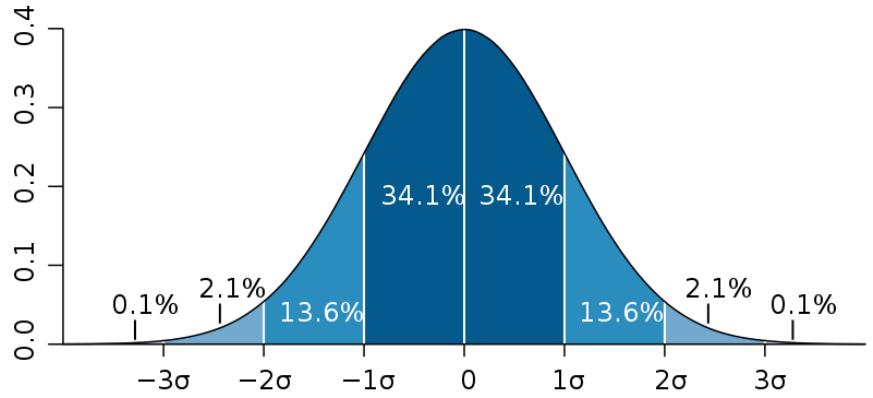

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https://en.wikipedia.org/wiki/File:Standard_deviation_diagram.svg

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