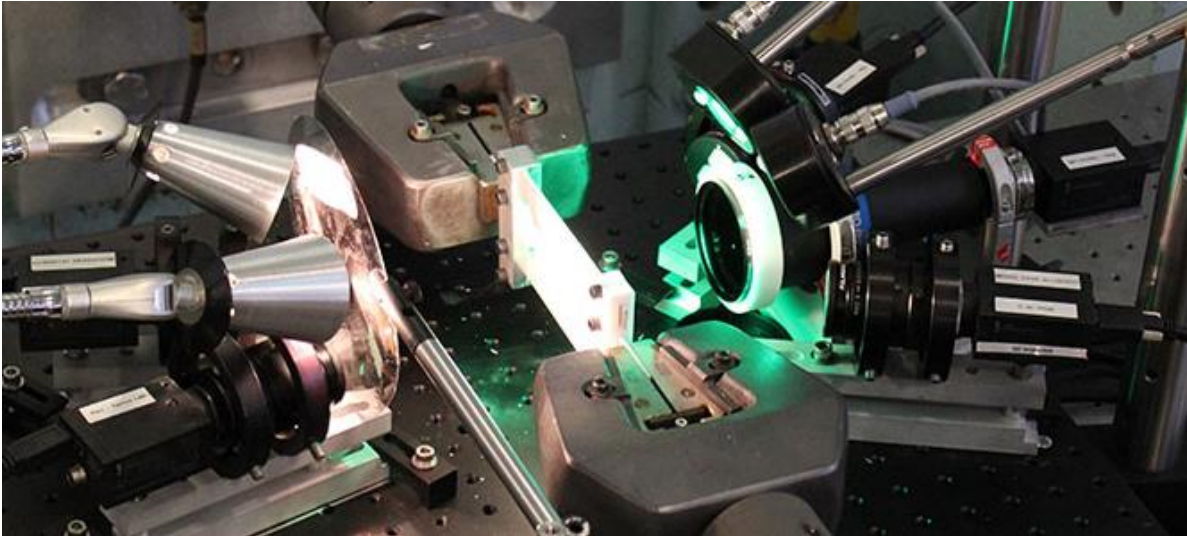


DIC 101



Elizabeth Jones and Amanda Jones
Sandia National Laboratories



Welcome to DIC 101!

Course Instructors

- ▶ Special thanks to Dave Johnson for video editing



Elizabeth Jones

Sandia National Laboratories



Amanda Jones

Sandia National Laboratories

Outline

- ▶ Basic, high-level DIC concepts
- ▶ Description of the GPG
- ▶ Design of DIC measurements
- ▶ Preparation for DIC measurements
- ▶ Camera calibration
- ▶ DIC processing techniques
- ▶ Strain calculations
- ▶ DIC reporting requirements

Course Description

- ▶ Follows the *Good Practices Guide for DIC* (GPG)
- ▶ Developed by the International Digital Image Correlation Society (iDICs)
- ▶ Focuses on practical applications of DIC rather than theory or algorithms

Target Audience

- ▶ New practitioners, to supplement vendor-based or other formal training
- ▶ Experienced users, to refresh their fundamental knowledge, assist in troubleshooting, and align practices with larger DIC community

Download the GPG!

Before watching these videos, please download the *Good Practices Guide for DIC*, so you can follow along.

<https://doi.org/10.32720/IDICS/GPG.ED1>



Chapter 1: Introduction to DIC and the Good Practices Guide

- ▶ Keep the dots in the box
- ▶ 2D vs. Stereo DIC: main concepts
- ▶ Good Practices Guide

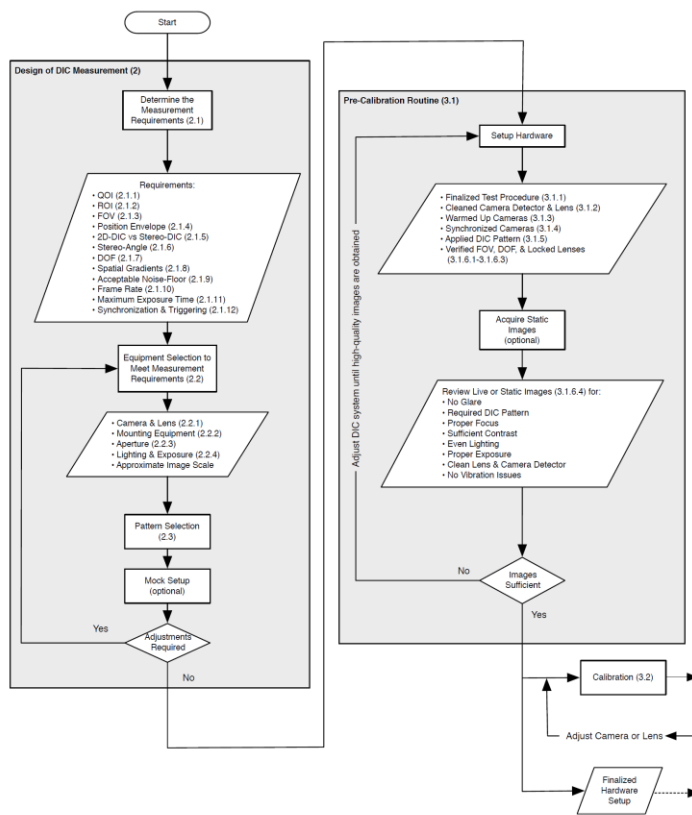
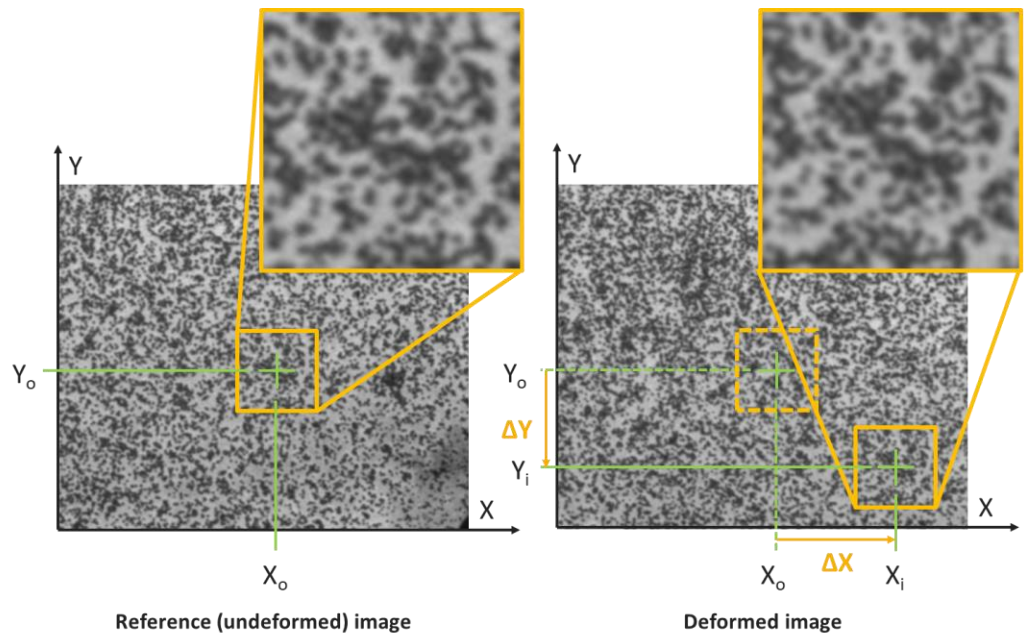


Figure A.1: Flow chart illustrating the main steps involved when conducting DIC measurements in conjunction with mechanical testing of a planar test piece (part 1).

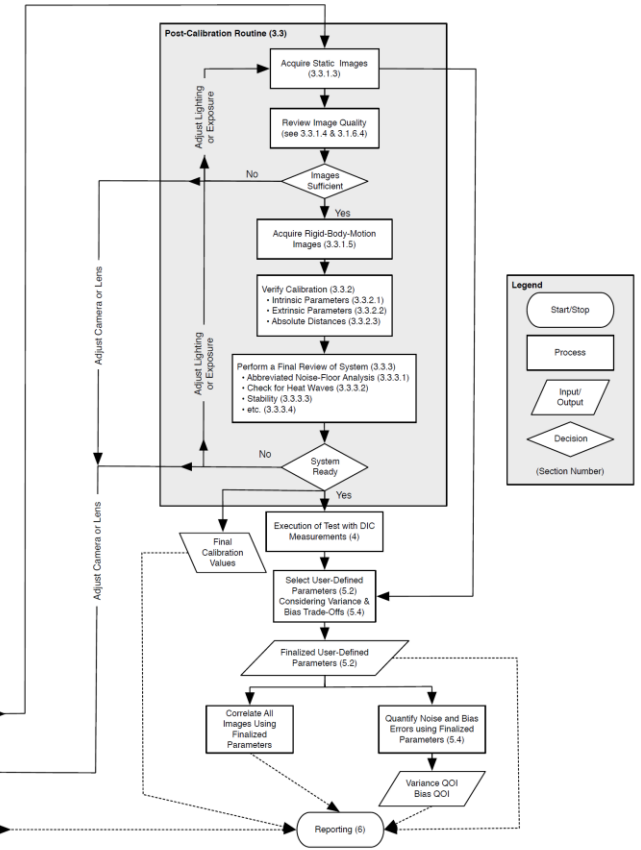


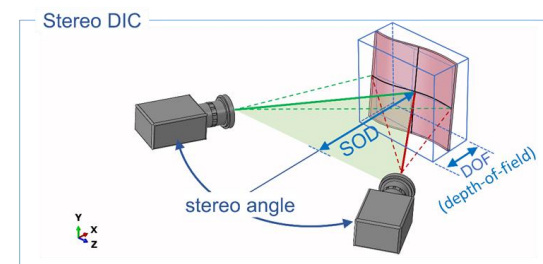
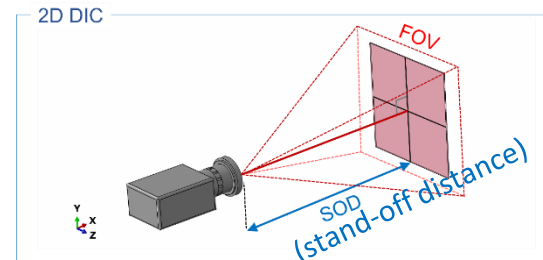
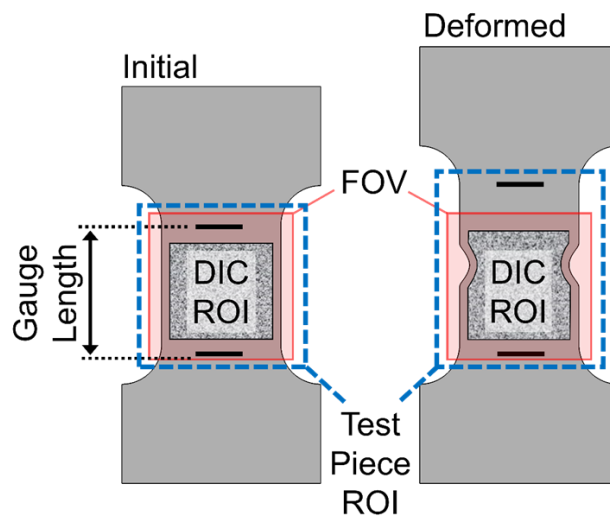
Figure A.2: Flow chart illustrating the main steps involved when conducting DIC measurements in conjunction with mechanical testing of a planar test piece (part 2).



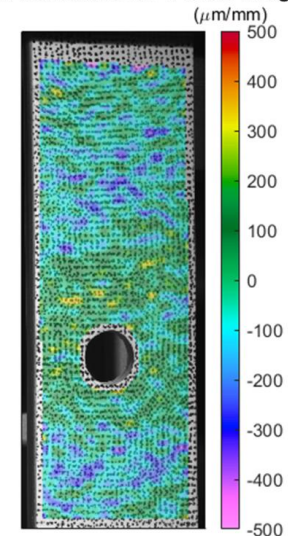
Chapter 2: Design of DIC Measurements

► Sec. 2.1: Measurement Requirements

- QOI, ROI, FOV
- 2D vs Stereo DIC
 - 2D DIC errors
 - Stereo angle selection
- Position envelop for hardware
- Spatial gradients
- Noise floor
- Frame rate
- Exposure time
- Synchronization and triggering

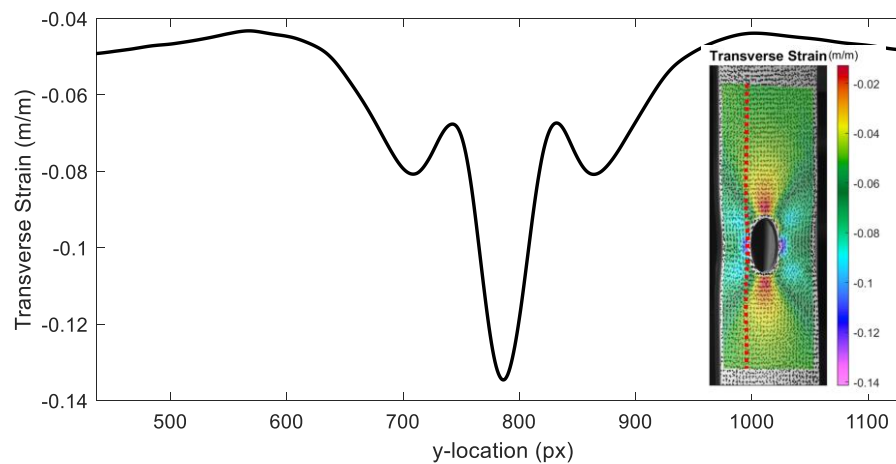


Noise of Transverse Strain Field
(from correlation of a static image)

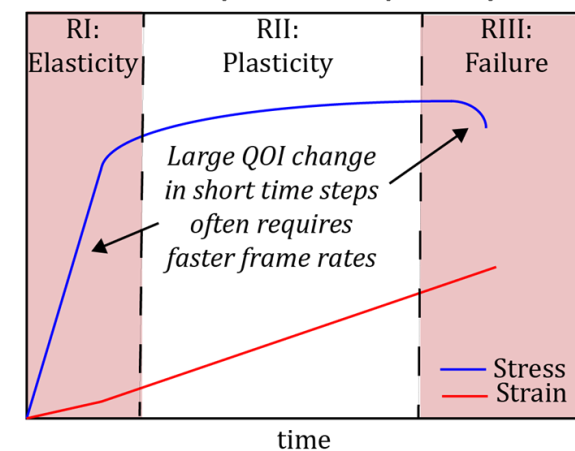


► Demo 01

- Setup overview
- QOI, ROI, FOV
- Stereo angle
- Focusing



Example 1: Metal plasticity



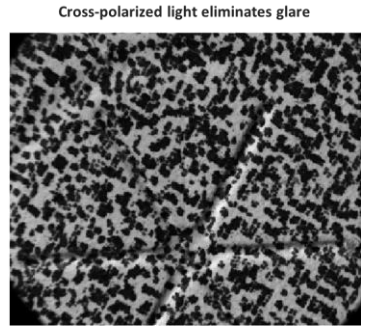
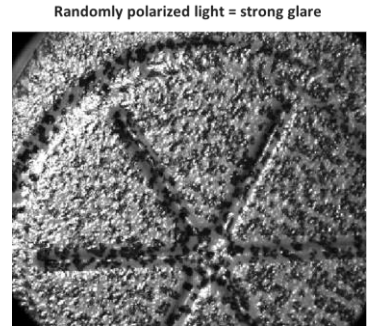
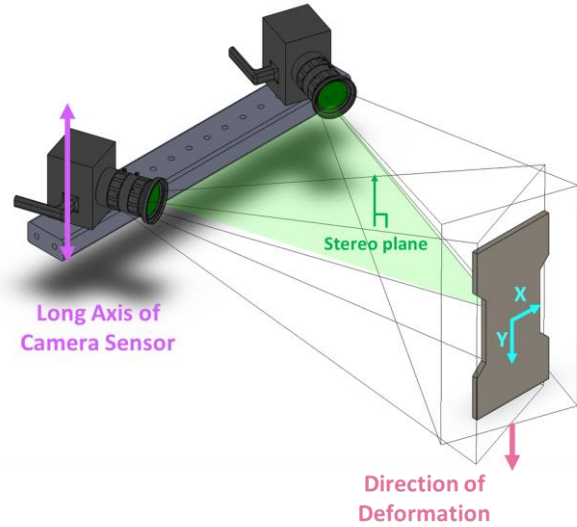


Chapter 2: Design of DIC Measurements

Sec. 2.2: Equipment and Hardware

- ▶ Lens selection
 - ▶ Focal length, stand-off distance, field-of-view
 - ▶ Prime vs zoom lens
- ▶ Camera selection
- ▶ Mounting system
- ▶ Recommended camera orientations
 - ▶ Sensor orientation
 - ▶ Rig orientation
- ▶ Aperture
- ▶ Lighting, exposure, gain, & contrast
- ▶ Cross polarized and diffuse light
- ▶ Heat waves

Focal Length	Stand-Off Distance	Field-of-View
↑	Constant	↓
↑	↑	Constant
Constant	↑	↑



Demo 02

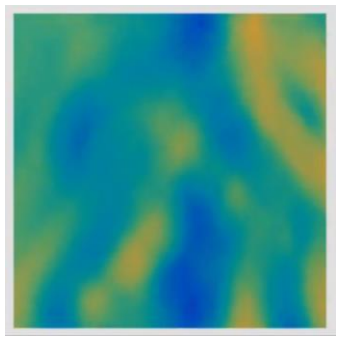
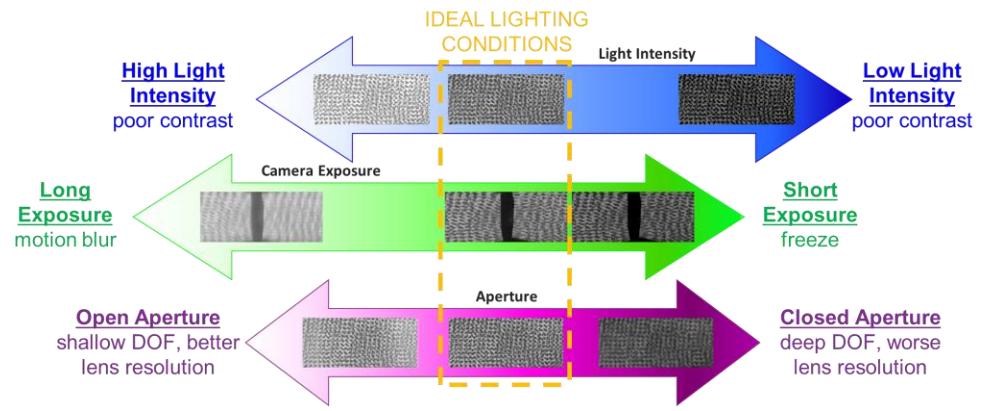
- ▶ Lens selection
 - ▶ Focal length, stand-off distance, field-of-view
 - ▶ Prime vs zoom lens

Demo 03

- ▶ Mounting system
- ▶ Camera orientation

Demo 04

- ▶ Aperture, lighting, exposure, gain, & contrast
- ▶ Cross-polarized light





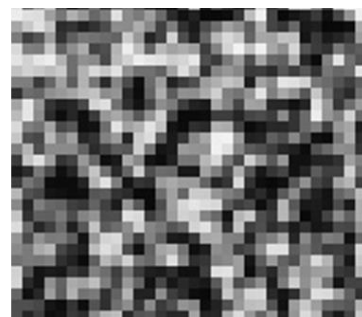
Chapter 2: Design of DIC Measurements

► Sec. 2.3: DIC Pattern

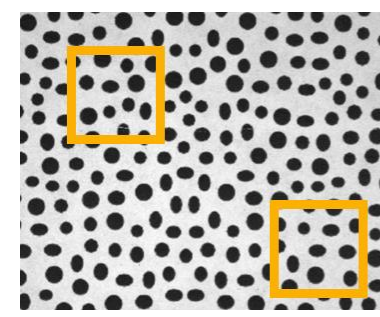
- Natural vs applied
- Size
- Variation
- Density
- Quality
- Reflections
- Compliance
- Bonding
- Fidelity
- Thickness
- Methods



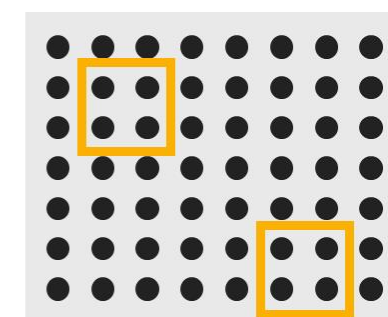
Appropriate size



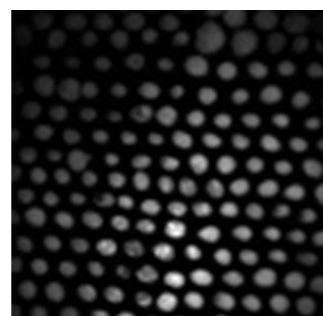
Too small – aliased



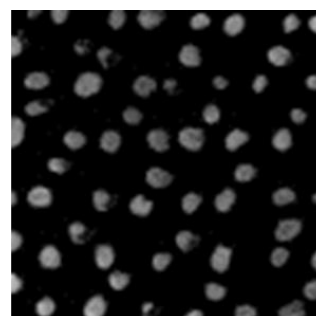
Random



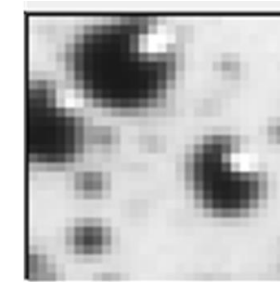
Oriented, regular



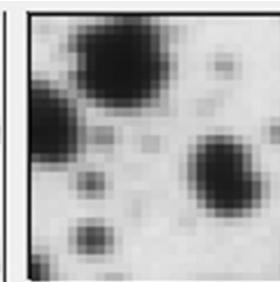
Appropriate density



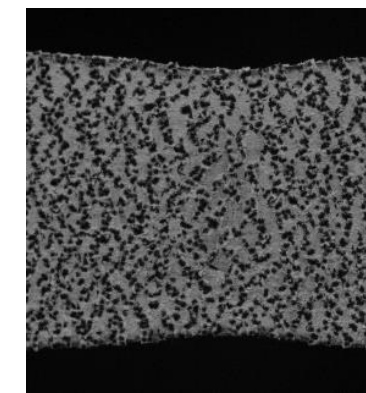
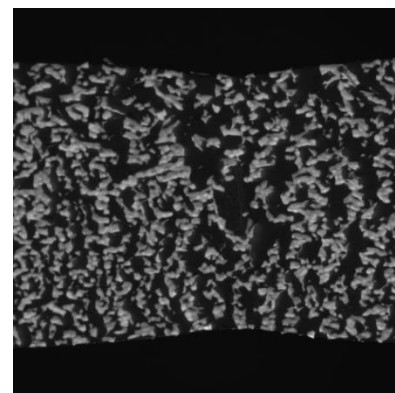
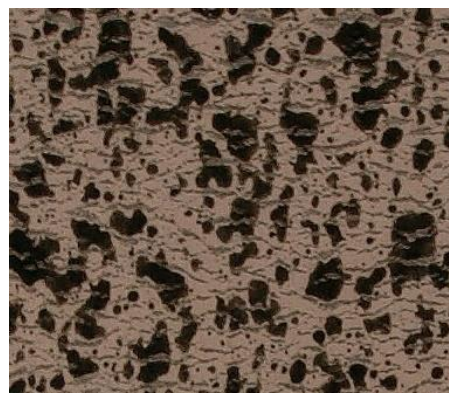
Sparse pattern



Specular reflection
on each speckle



Matte pattern





Chapter 3: Preparation for the Measurements

▶ Sec. 3.1: Pre-Calibration Routine

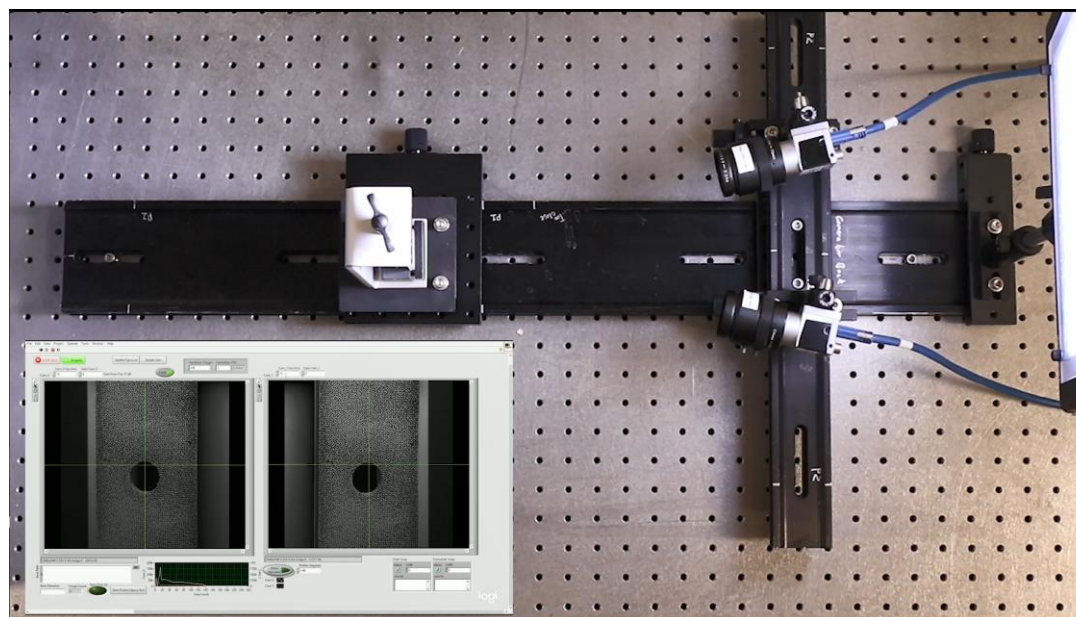
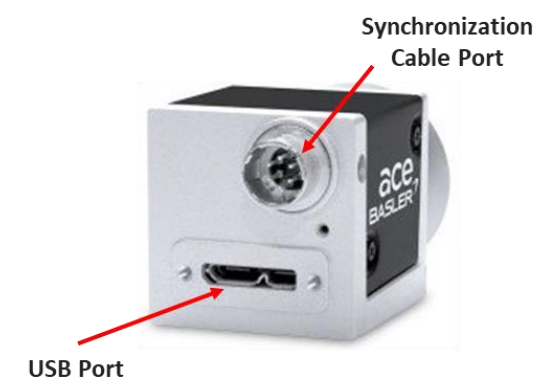
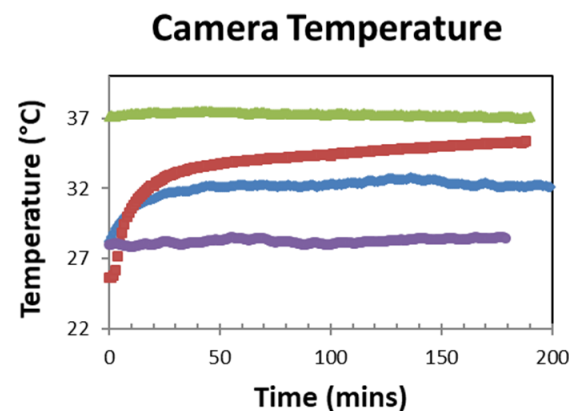
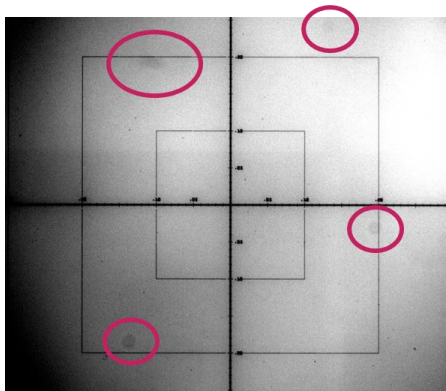
- ▶ Test procedure
- ▶ Cleanliness of equipment
- ▶ Camera warm-up
- ▶ Synchronization
- ▶ Review of system

▶ Demo 05

- ▶ Cleanliness of equipment

▶ Demo 06: Review system

- ▶ Position test piece and cameras
- ▶ Verify FOV, focus, DOF, magnification/SOD
- ▶ Adjust polarization filters.
- ▶ Lock adjustable components
- ▶ Review images, looking for
 - ▶ Glare
 - ▶ DIC pattern that is too coarse/fine
 - ▶ Defects in applied pattern
 - ▶ Out-of-focus regions
 - ▶ Poor contrast
 - ▶ Non-uniform lighting
 - ▶ Dirt or foreign object on lens
 - ▶ Vibrations

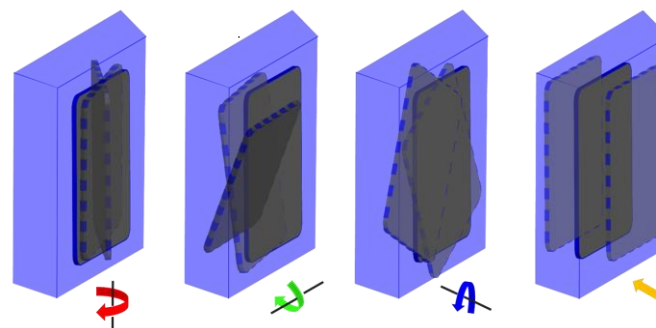
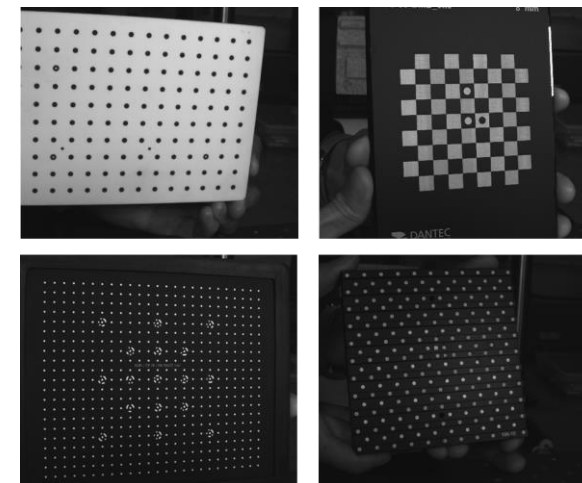
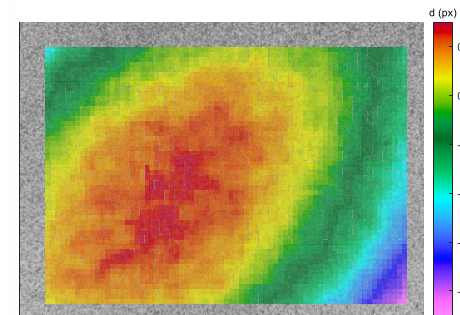
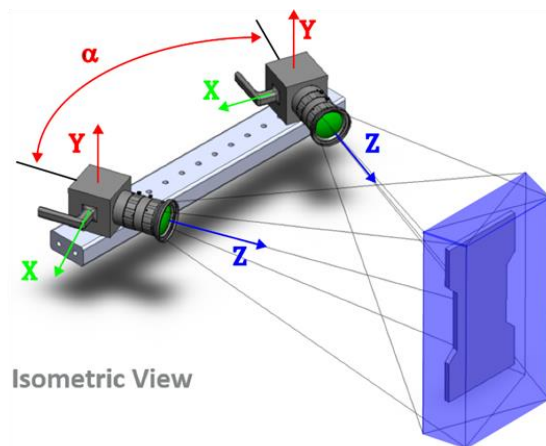




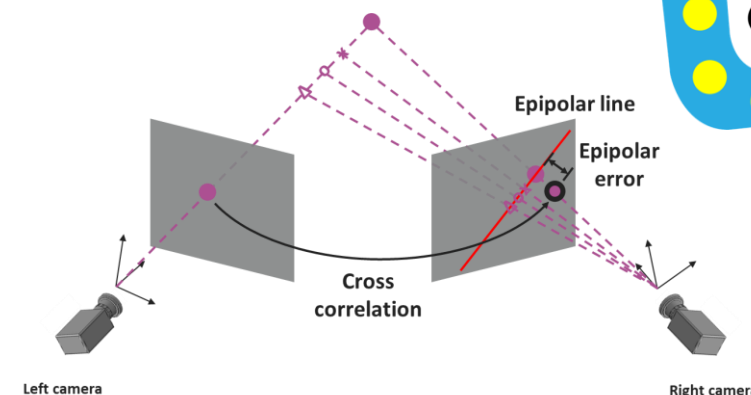
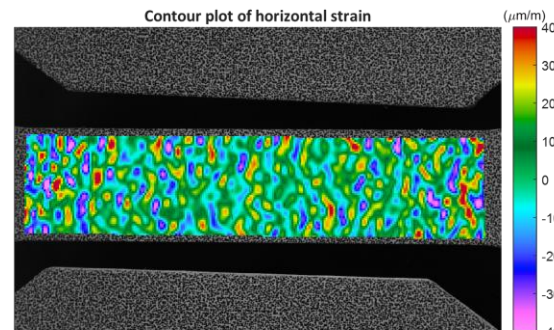
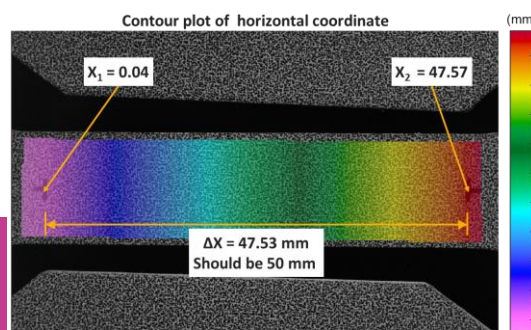
Chapter 3: Preparation for the Measurements

► Sec. 3.2.3.3: Calibration

- Intrinsic parameters
- Extrinsic parameters
- Lens distortions
- Calibration target
- Volume to calibrate
- Review parameters
- Focal length (px)
- What's wrong with my calibration?
- Verification
 - Lens distortions
 - Absolute lengths/distances
 - Noise floor
 - Epipolar error



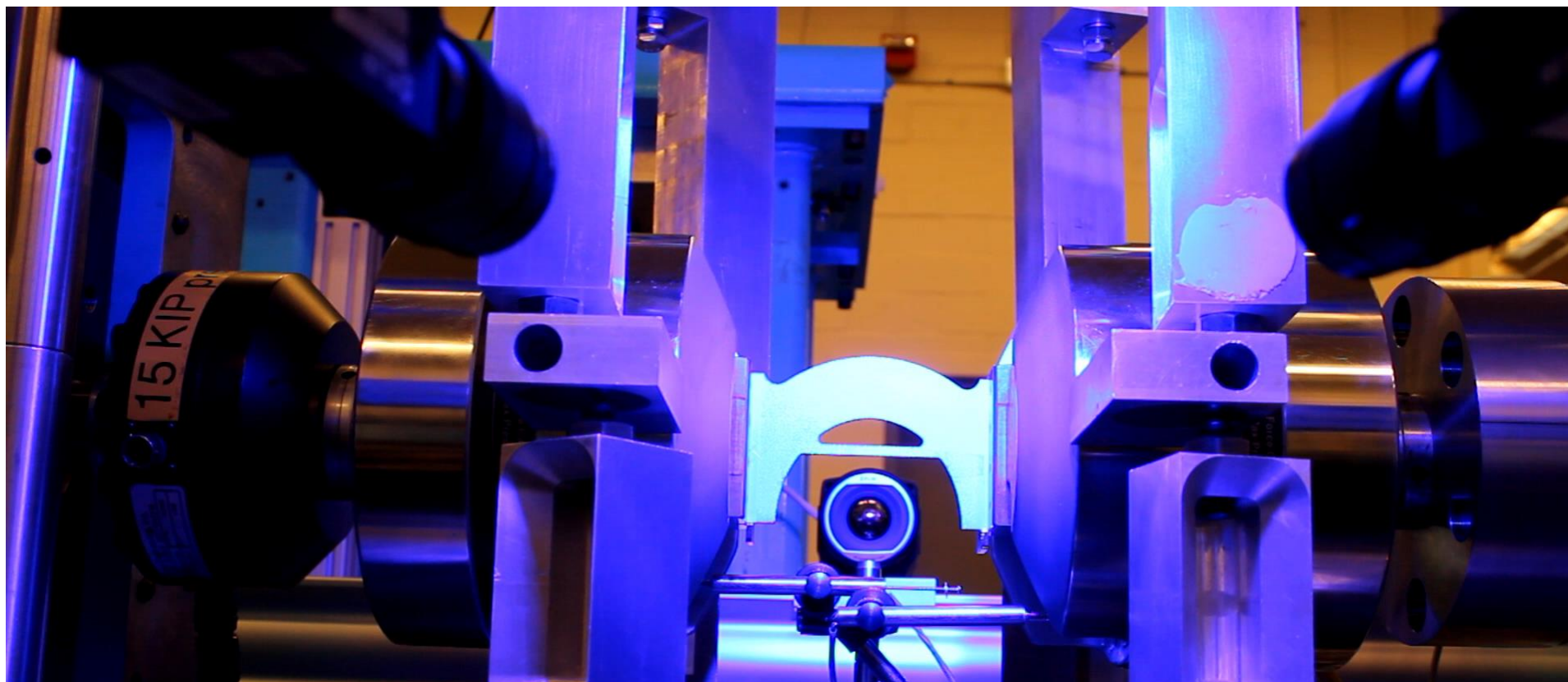
► Demo 07: Calibration





Chapter 4: Execution of the Test

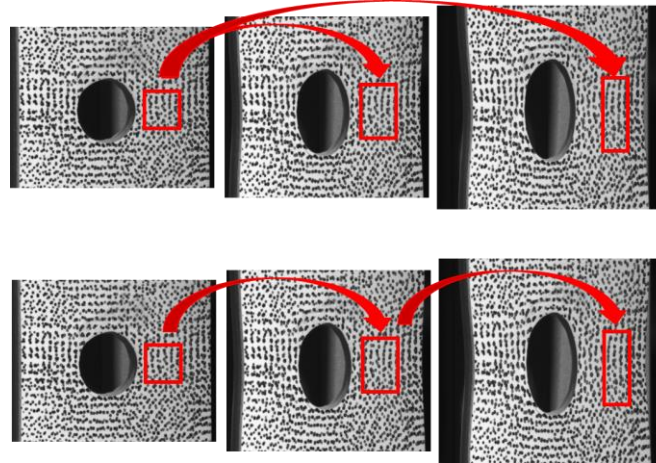
- ▶ Review all data acquisition systems
- ▶ Execute the test



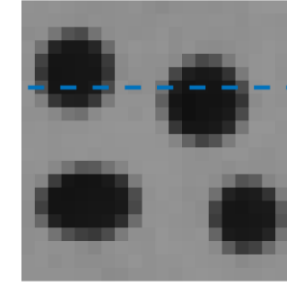
Chapter 5: Processing of DIC Images

► Sec. 5.1-5.2: DIC software and user-defined settings

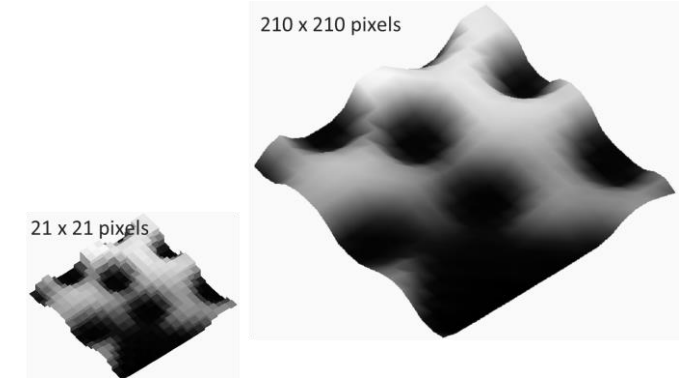
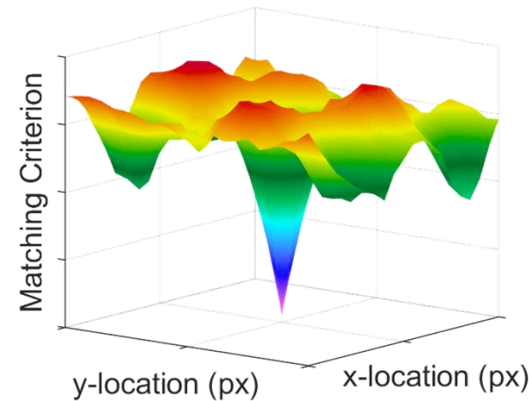
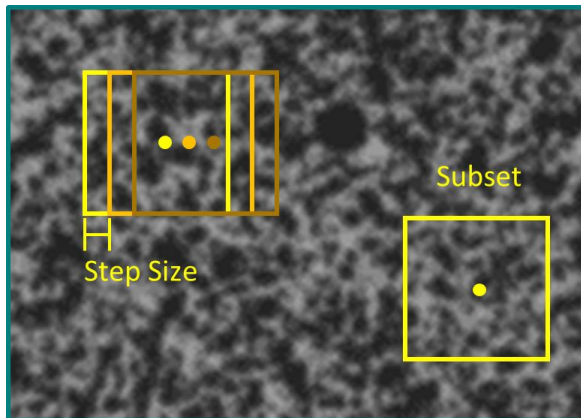
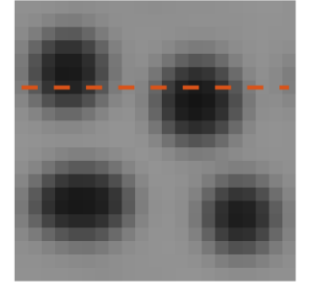
- <https://idics.org/resources/>
- <https://sem.org/dic-challenge/>
- Reference image
- Image pre-filtering
- Matching criterion
- Subset shape function
- Interpolation
- Subset size
- Step size
- Thresholds



DIC Challenge Sample 6
Original Image



Gaussian Filter
Kernel 5 px; STD 1 px



$$\xi = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} u \\ v \end{bmatrix} + \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} + \begin{bmatrix} \frac{\partial^2 u}{\partial x \partial y} \\ \frac{\partial^2 v}{\partial x \partial y} \end{bmatrix} \Delta x \Delta y + \begin{bmatrix} \frac{\partial^2 u}{\partial x^2} & \frac{\partial^2 u}{\partial y^2} \\ \frac{\partial^2 v}{\partial x^2} & \frac{\partial^2 v}{\partial y^2} \end{bmatrix} \begin{bmatrix} (\Delta x)^2 \\ (\Delta y)^2 \end{bmatrix}$$

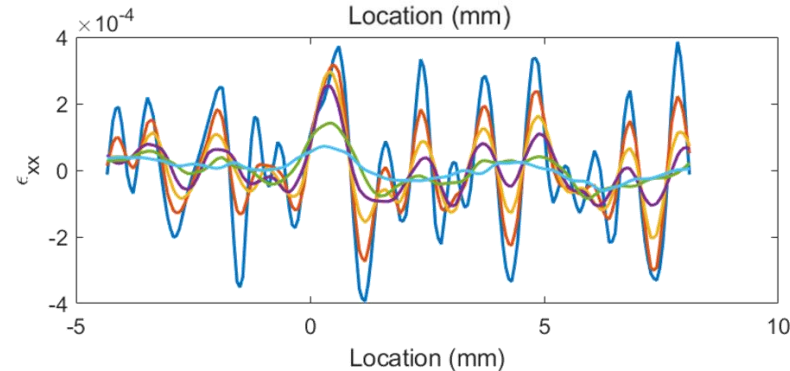
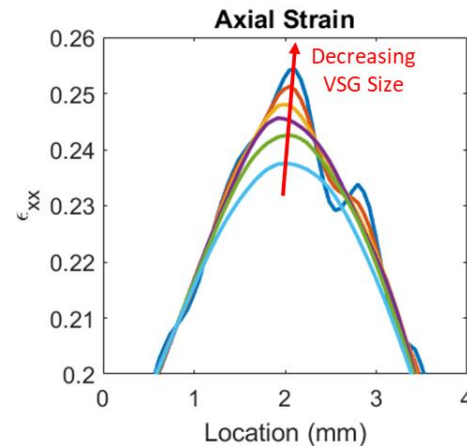
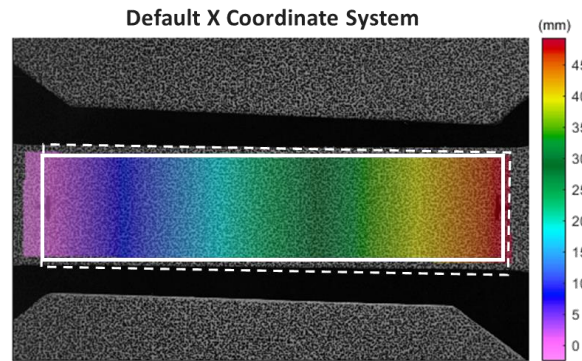


Chapter 5: Processing of DIC Images

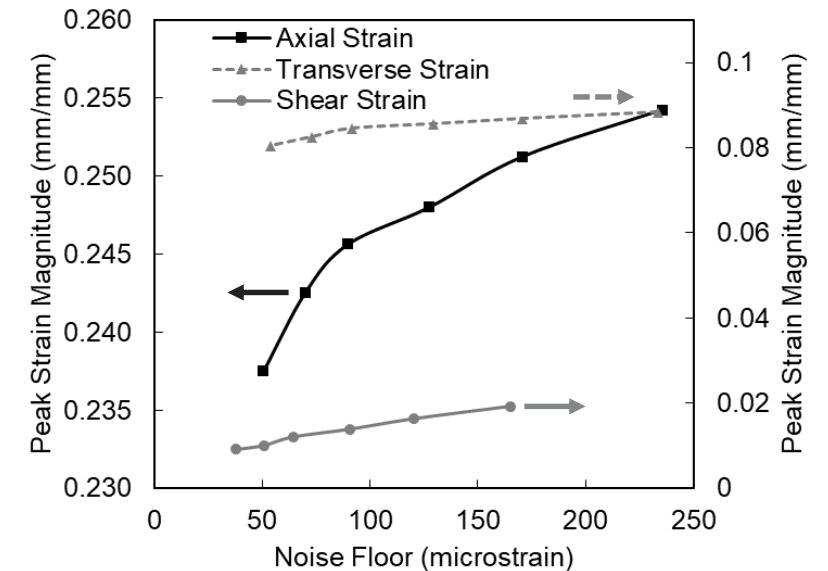
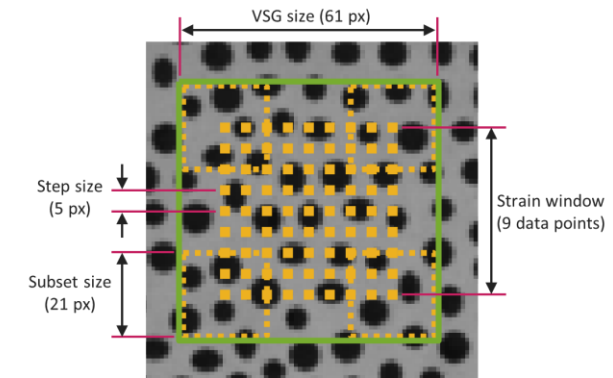
► Sec. 5.3: Strain Calculations + Sec. 5.4: Uncertainty Quantification

- Coordinate system
- VSG size
- Variance vs Bias errors
- VSG study

1. Select subset & step size
2. Select noise image and high-gradient image
3. Analyze with different settings
4. Extract a line cut
5. Assess convergence
6. Quantify noise
7. Balance variance and bias



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





Chapter 6: Reporting Requirements

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 Acquisition Rate	15 Hz
Patterning Technique*	Base coat of white sp
Pattern Feature Size (approximate)	5 pixels / 0.2 mm

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

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.