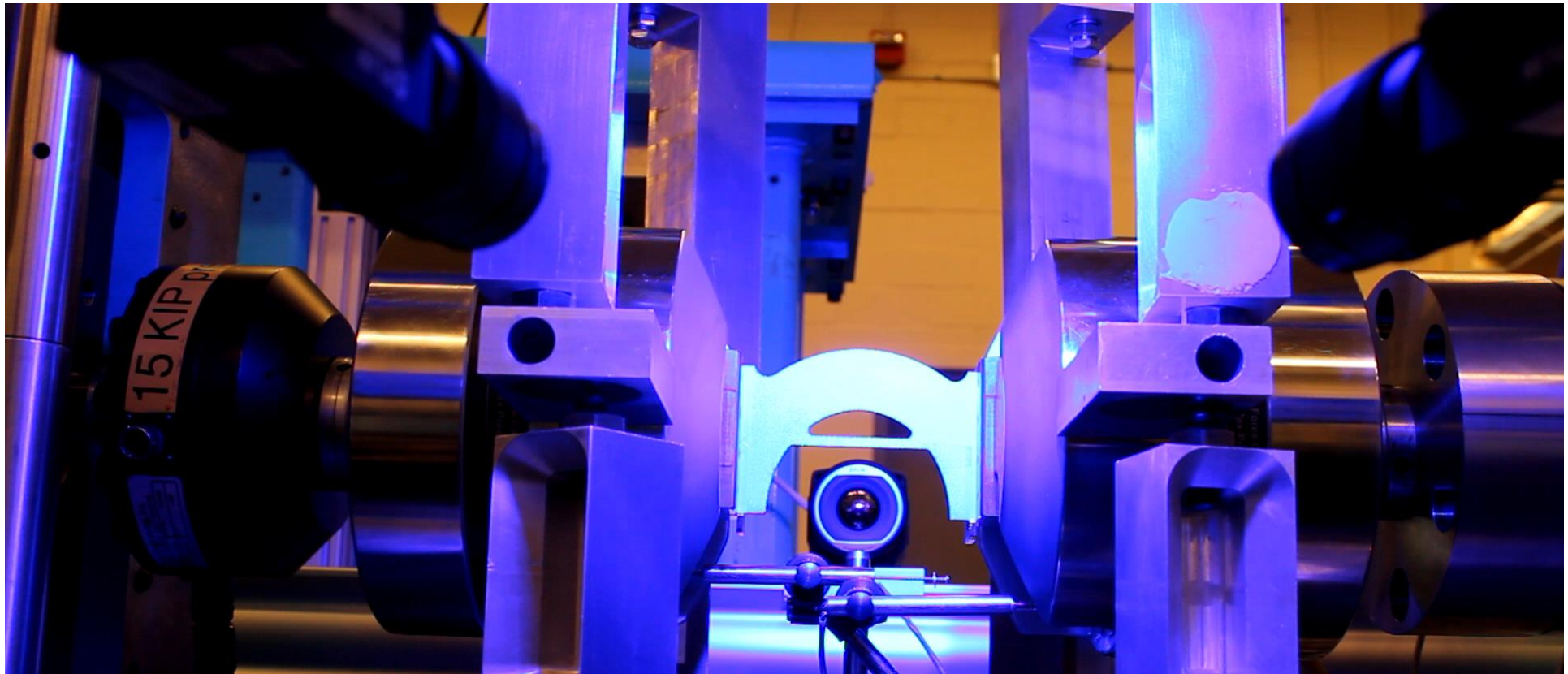
CHAPTER 4:
EXECUTION OF THE TEST

Review all data acquisition systems

- Correct file name, location, storage capacity for DIC images
- Correct test procedure or macro
- Force signals and other measurement signals are set to record and are synchronized with DIC images
- Triggering of the test frame and/or DIC images is ready
  - Caution 4.1: Ensure at least one image is acquired of the test piece prior to any applied force or displacement.
- Lights are turned on, exposure is correct, and frame rate is correct



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

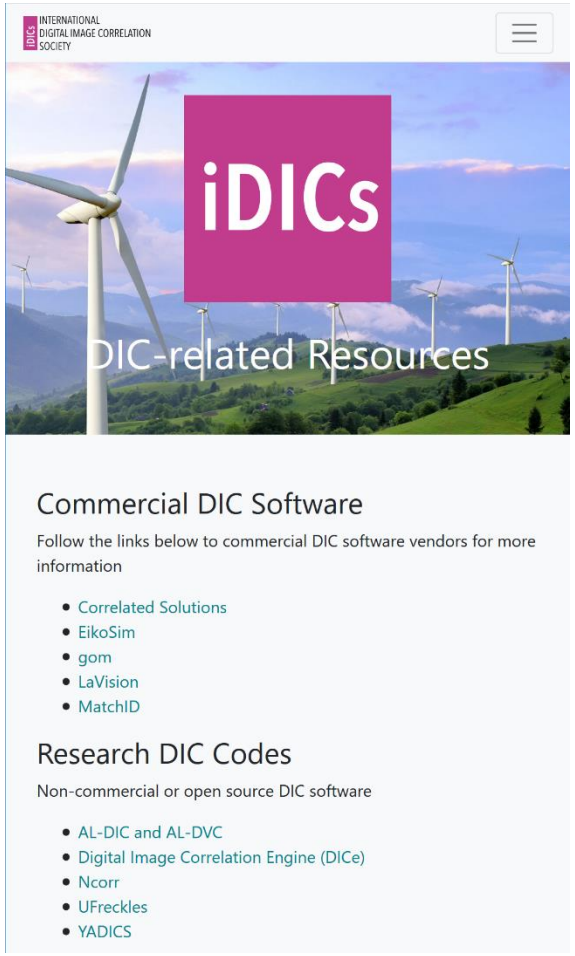
CHAPTER 5: PROCESSING OF DIC IMAGES

SEC. 5.1: DIC SOFTWARE

SEC. 5.2: USER-DEFINED PARAMETERS

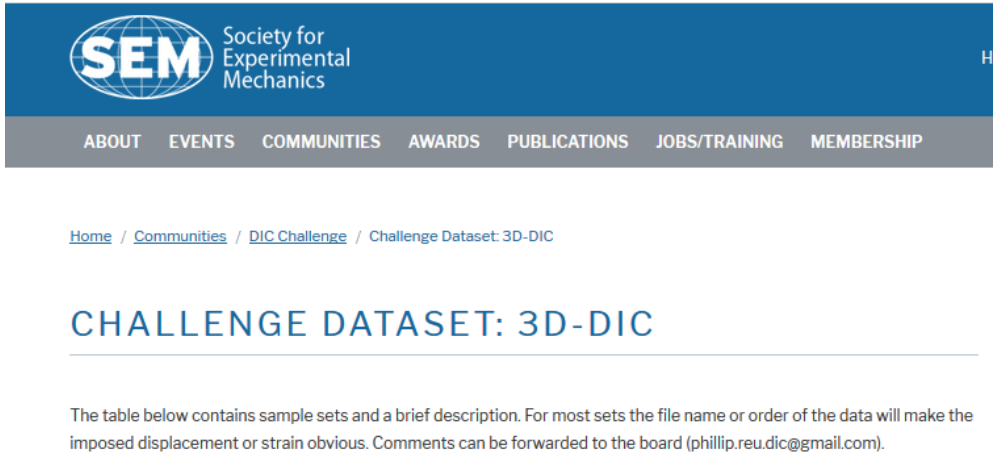
DIC Software
Sec. 5.1

- Both commercially and open source codes are available
- https://idics.org/resources/
- Speak with vendors at the conference



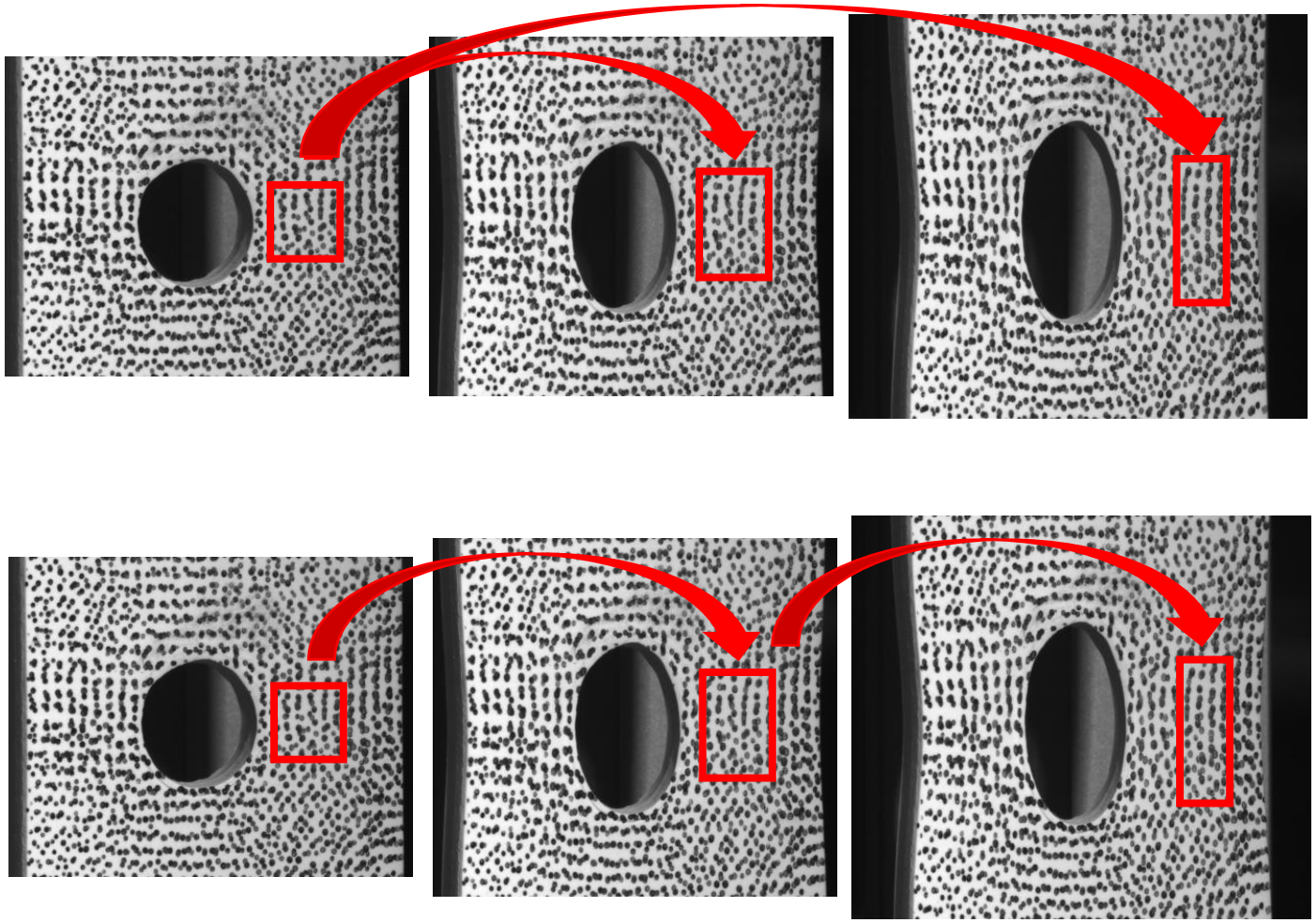
- The DIC Challenge provides vetted images
- https://sem.org/dic-challenge/
- PL Reu, et al., *Exp. Mech.* (2018) 58:1067-1099

- Standardized images facilitate:
  - Exploring the “black box” of proprietary/commercial DIC software
  - Verifying custom software implementations



Reference Image
Sec. 5.2.1

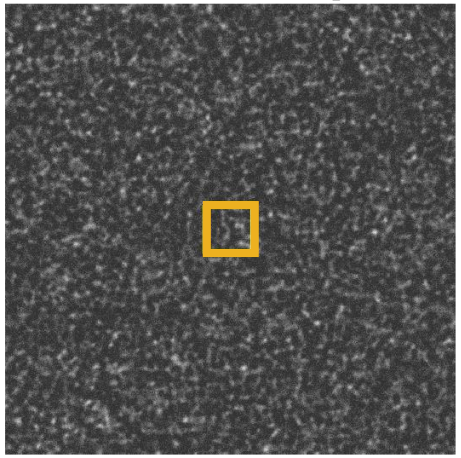
- DIC tracks motion, in the Lagrangian sense, of a set of interrogation points, defined on a reference image:
  - **Standard Correlation: A single reference image**
    - Caution 5.1: Collect reference image prior to any displacement or force
    - Tip 5.1: You can collect several (e.g. 10) images of stationary test piece and average, creating an approximately noise-free reference
  - **Incremental Correlation**
    - Each image is correlated to prior image with the drawback of higher error
  - **Partitioned correlation**
    - A test series is broken into sub-series and each batch is correlated back to the first image in that sub-series



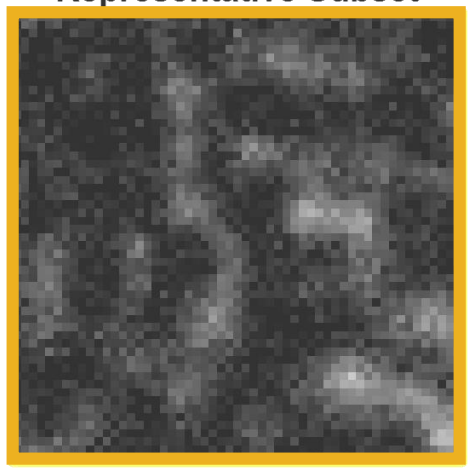
Correlation example: Reference image

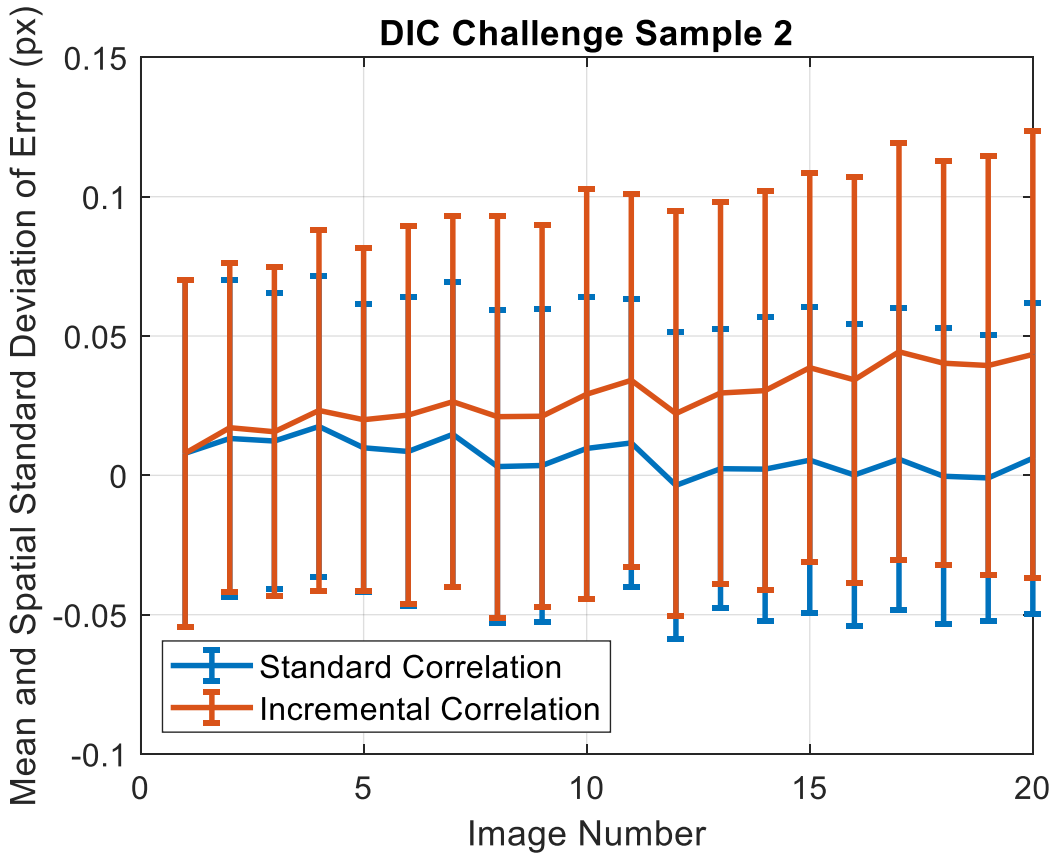
- ***DIC Challenge Sample 2***
  - Rigid translation
  - Low signal/noise ratio

Reference Image



Representative Subset





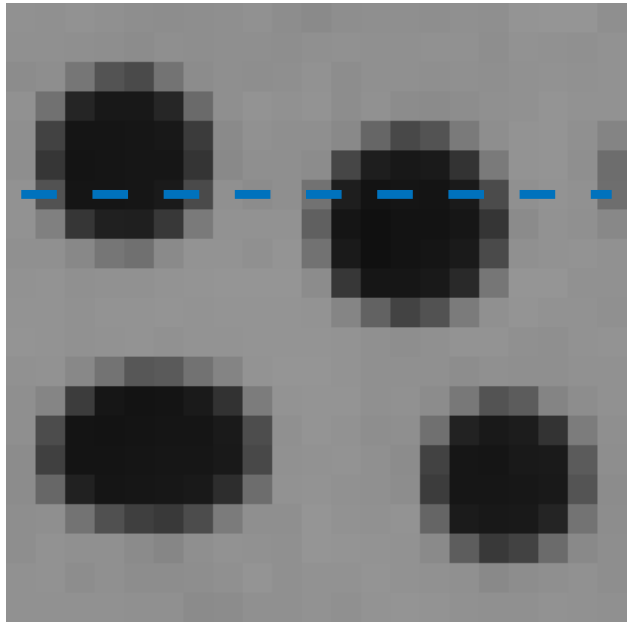
- *Correlation parameters*
  - Gaussian image prefilter with kernel size 5 px
  - Affine shape function
  - Bicubic spline interpolant
  - ZNSSD matching criterion
  - Subset size 55
  - Step size 20 (529 points total)

Noise is higher and mean error accumulates over time/image number with incremental correlation.

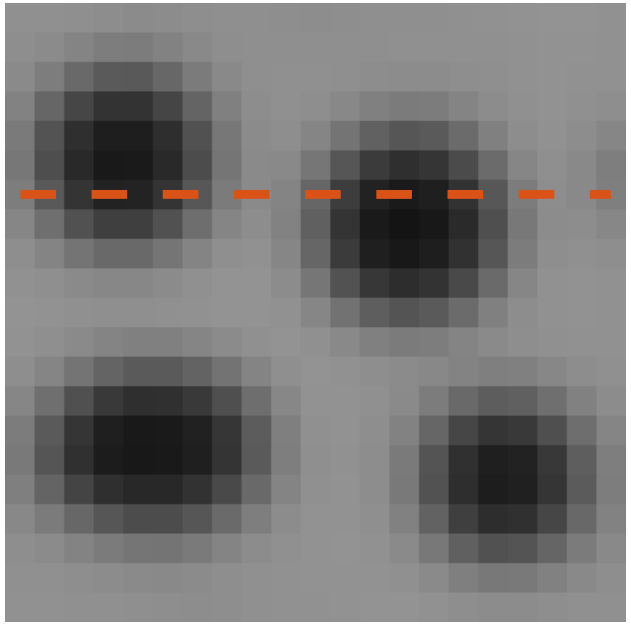
Pre-Filtering of Images
Sec. 5.2.2

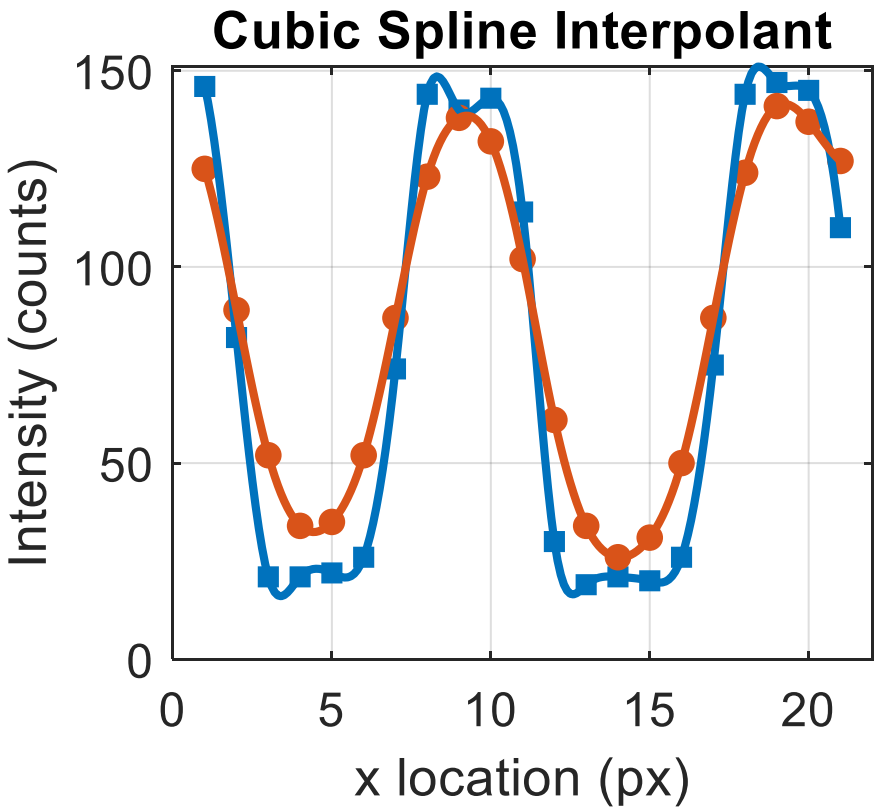
- Subset interpolants often perform better with smooth spatial gradients in image intensity (e.g. Gaussian low pass filter)
- Low pass filter can also reduce image noise and effects of aliased features
- Caution 5.2: Low-pass filters can also bias the results

DIC Challenge Sample 6
Original Image



Gaussian Filter
Kernel 5 px; STD 1 px



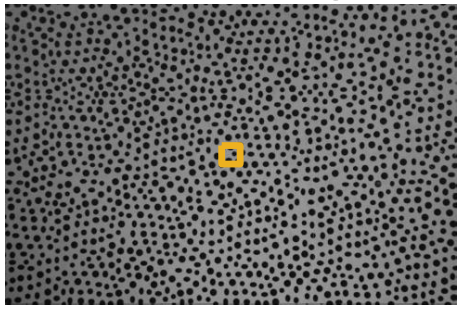


Know if you are pre-filtering your images! This is a reporting requirement.

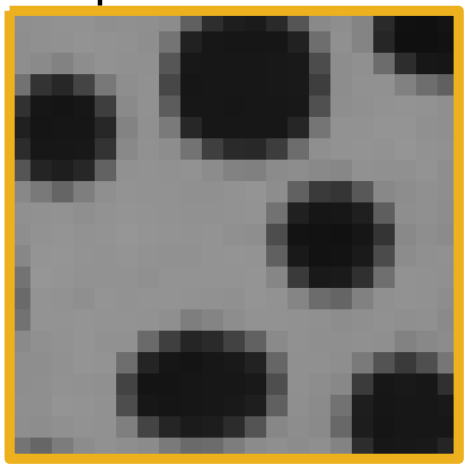
Correlation example: Pre-filtering

- ***DIC Challenge Sample 6***
  - Rigid translation in sub-pixel increments
  - Sharp-edged speckles

Reference Image



Representative Subset



- *Correlation parameters*
  - Affine shape function
  - Bicubic spline interpolant
  - ZNSSD matching criterion
  - Subset size 21
  - Step size 5 (5594 points total)

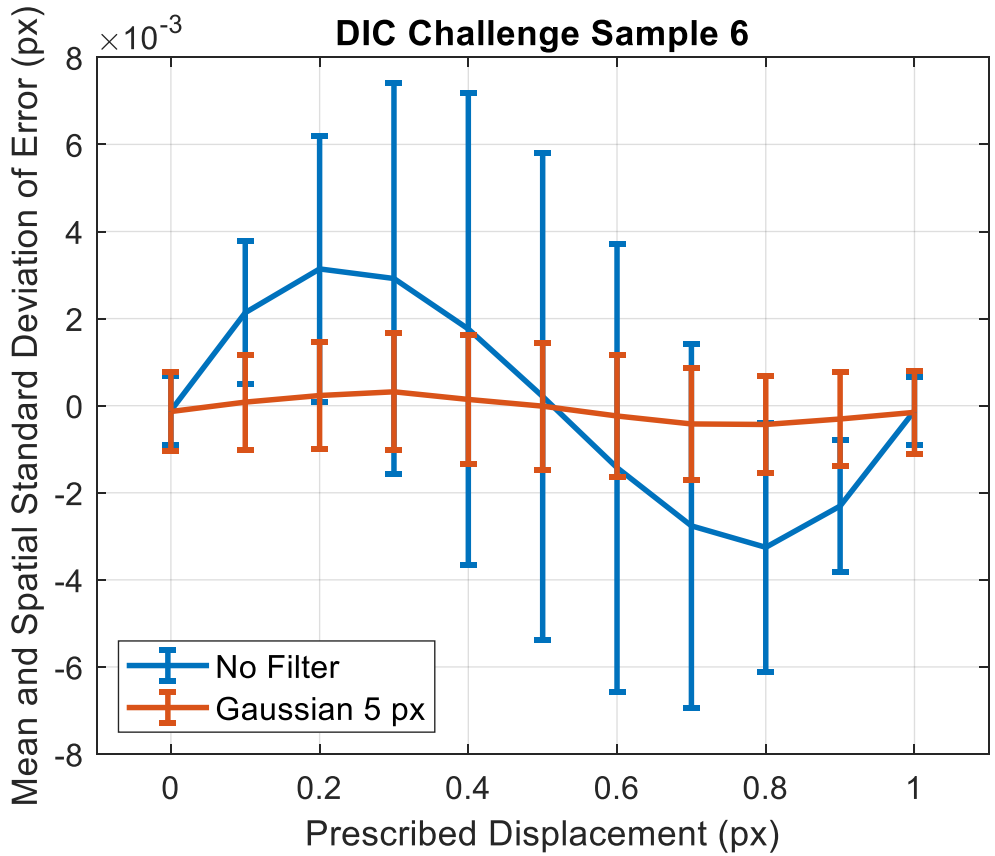
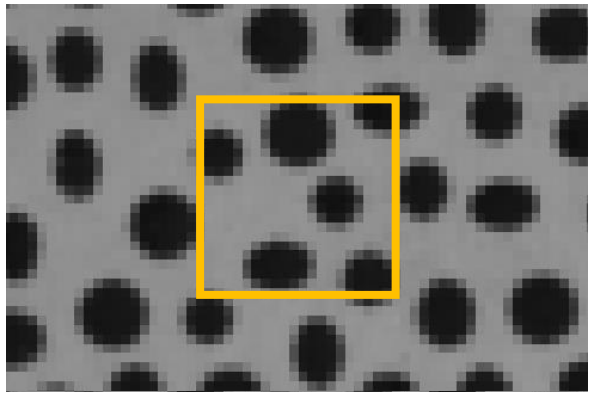


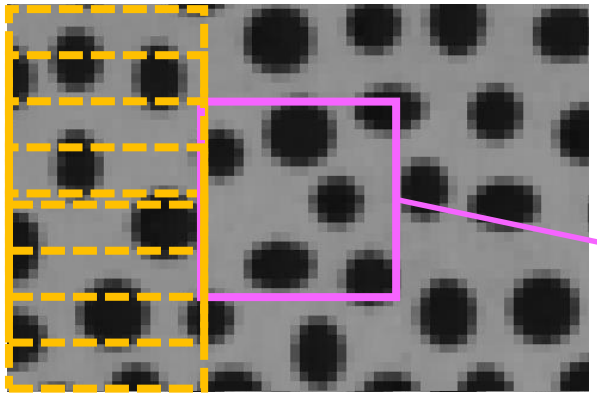
Image prefiltering reduces both bias and variance errors.

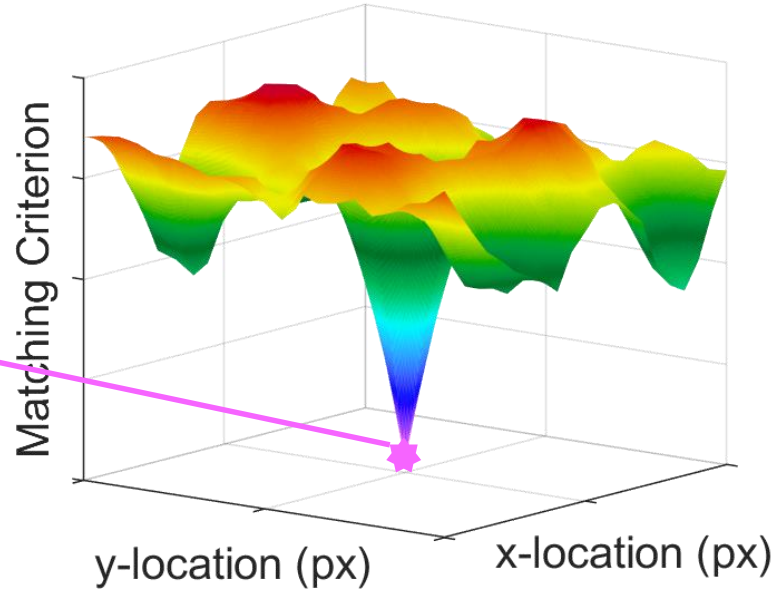
Matching criterion
Not in the guide!

Subset to find (reference image)



ROI (deformed image)





$$\chi^2 = \sum_i (G_i - F_i)^2$$

χ – is the value of the matching criterion
F – is the reference image
G – is the deformed image
i – is the pixel in the subset

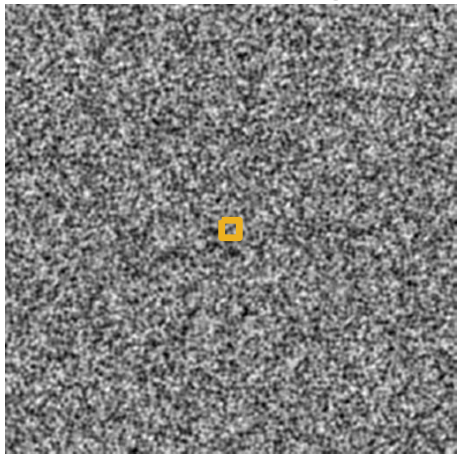
Examples of Matching Criteria

1. Sum Squared Difference (SSD)
2. Normalized Sum Squared Difference (NSSD)
3. Zero Normalized Sum Squared Difference (ZNSSD)

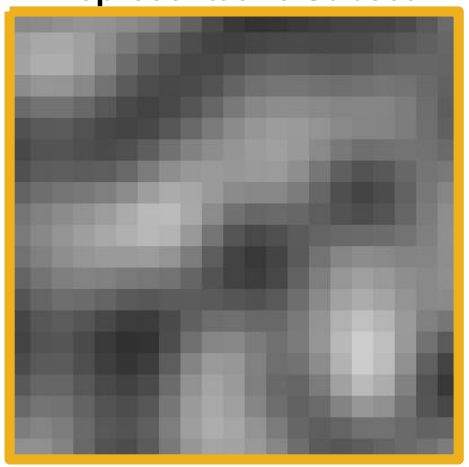
Correlation example: Matching criterion

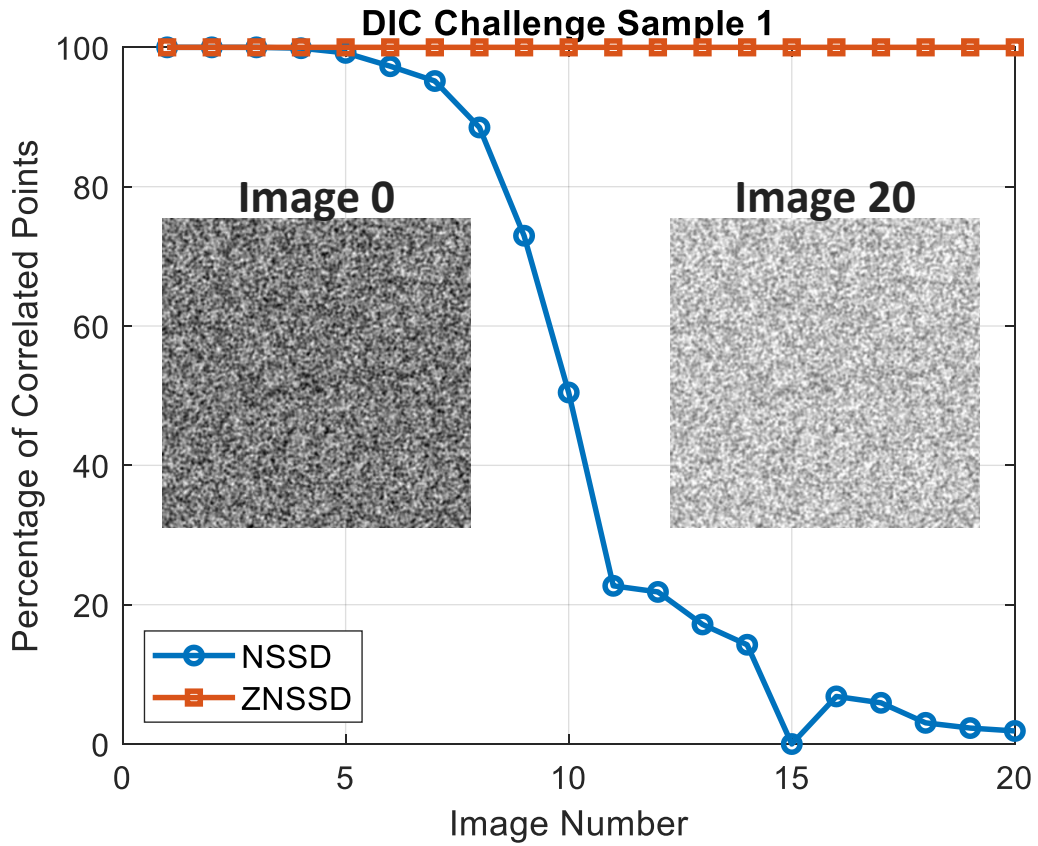
- ***DIC Challenge Sample 1***
  - Rigid translation
  - Varying intensity and contrast

Reference Image



Representative Subset



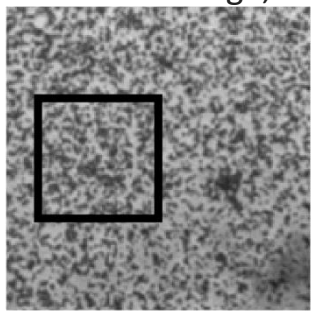


- *Correlation parameters*
  - Gaussian image prefilter with kernel size 5 px
  - Affine shape function
  - Bicubic spline interpolant
  - Single reference image
  - Subset size 21
  - Step size 10 (2402 points total)

Only the ZNSSD matching criterion is able to compensate for the varying intensity and contrast.

Subset Shape Function
Sec. 5.2.3

Reference image, F

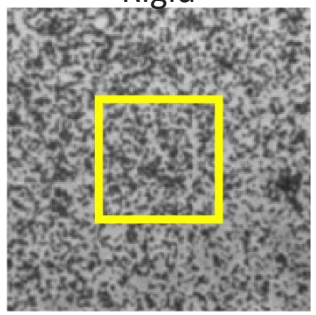


$$\chi^2 = \sum_i (G_i(\xi) - F_i)^2$$

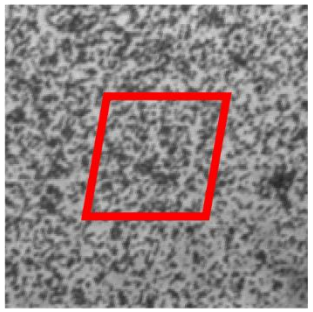
χ – is the value of the matching criterion
F – is the reference image
G – is the deformed image
i – is the pixel in the subset
ξ – is the subset shape function

$$\xi = \underbrace{\begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} u \\ v \end{bmatrix}}_{\text{Rigid}} + \underbrace{\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}}_{\text{Affine}} + \underbrace{\begin{bmatrix} \frac{\partial^2 u}{\partial x \partial y} \\ \frac{\partial^2 v}{\partial x \partial y} \end{bmatrix} \Delta x \Delta y}_{\text{Irregular}} + \underbrace{\begin{bmatrix} \frac{\partial^2 u}{\partial x^2} & \frac{\partial^2 u}{\partial y^2} \\ \frac{\partial^2 v}{\partial x^2} & \frac{\partial^2 v}{\partial y^2} \end{bmatrix} \begin{bmatrix} (\Delta x)^2 \\ (\Delta y)^2 \end{bmatrix}}_{\text{Quadratic}}$$

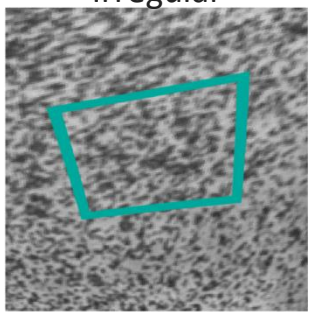
Rigid



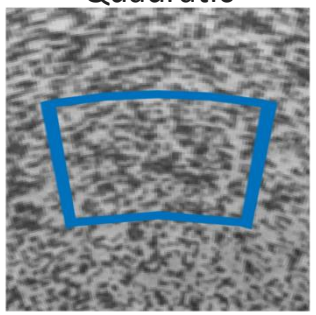
Affine



Irregular

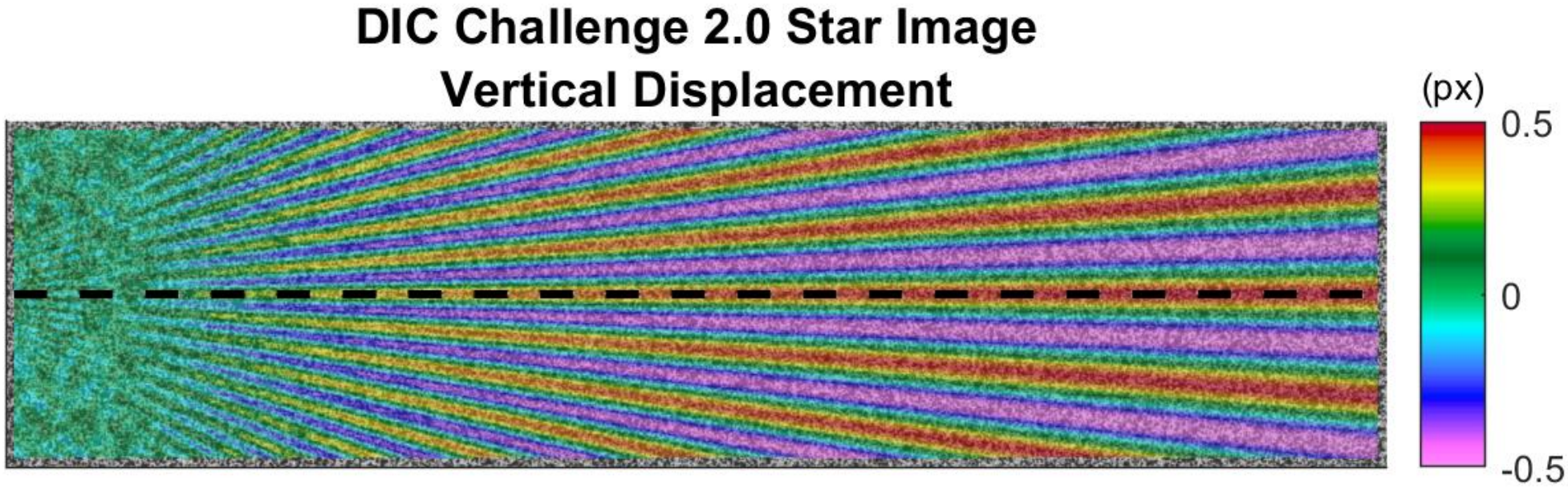


Quadratic



- Lower order shape functions cancel more noise, but have less accuracy
- Higher order shape functions are more accurate, but more noisy
- Some software packages have adaptive shape functions

Correlation example: Subset shape function

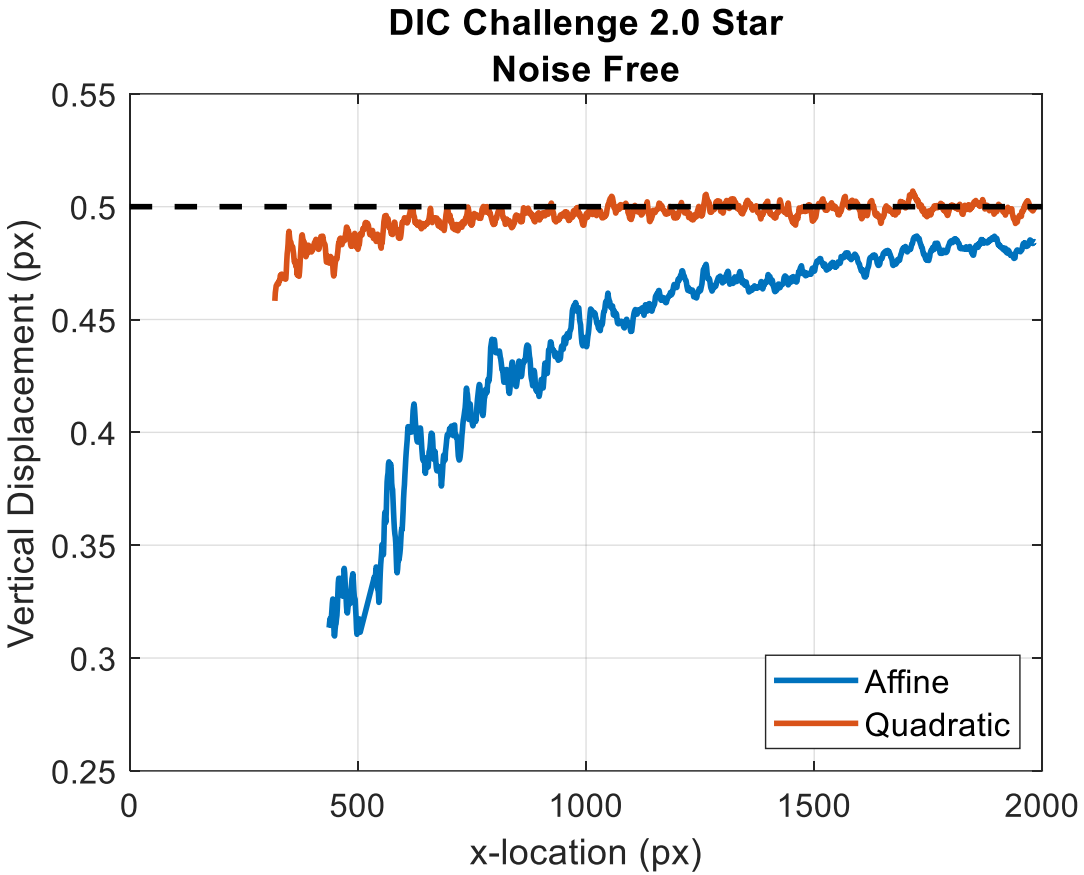


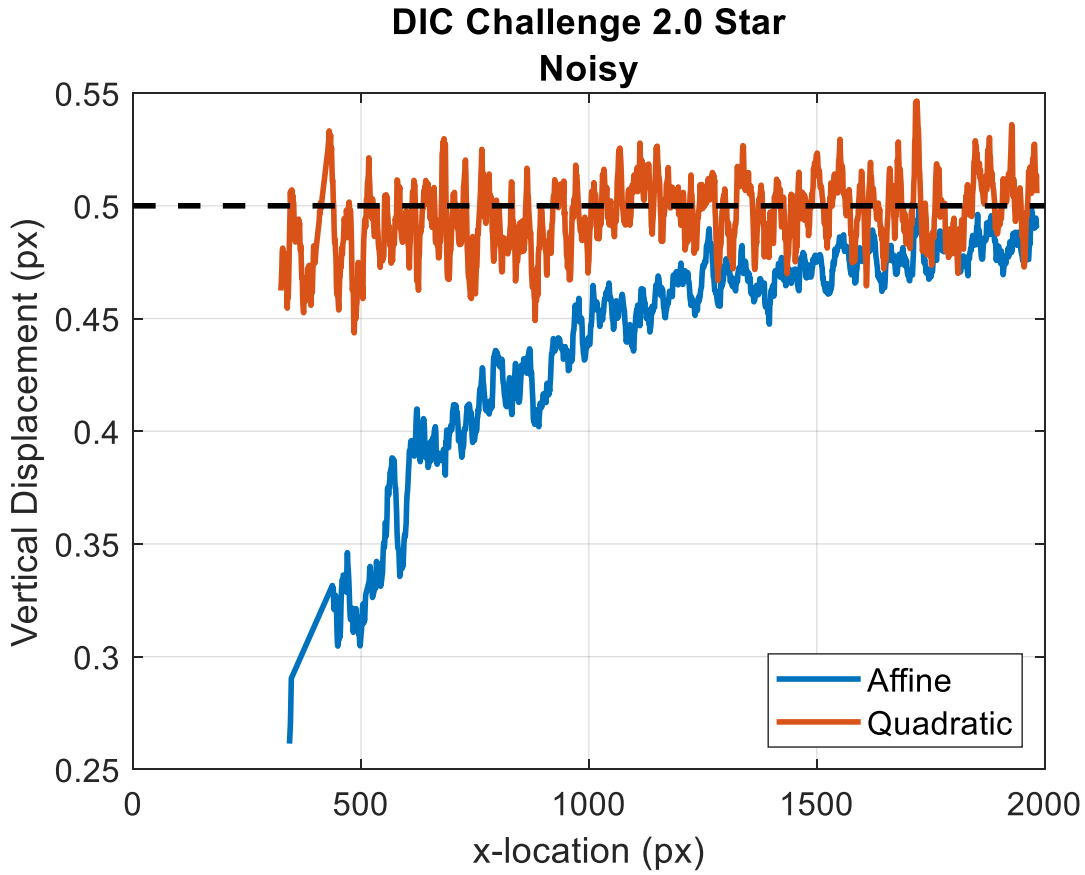
- Prescribed vertical displacement is sinusoidal
- Large period / low frequency on the right side
- Small period / high frequency on the left side
- Constant amplitude of 0.5 px along the horizontal center line cut
- Amplitude attenuated on left as shape function is inadequate to represent underlying deformation

Correlation Parameters

- No prefiltering
- Bicubic spline interpolant
- Subset size 21
- Step size 1

Correlation example: Subset shape function





Quadratic shape function provides better spatial resolution, but is more susceptible to image noise.

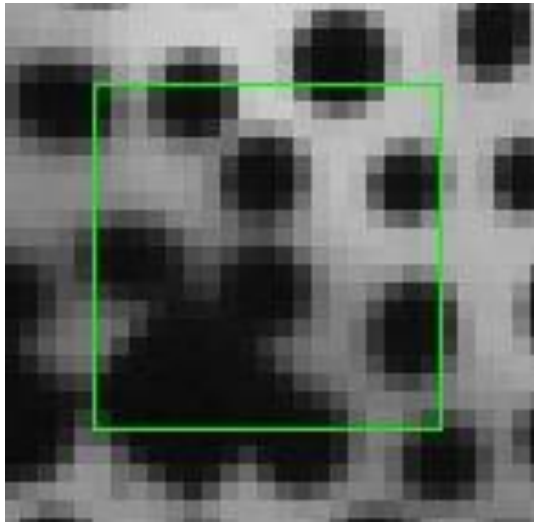
Interpolant
Sec. 5.2.4

Interpolation allows for subpixel precision

Types of interpolants

1. Linear (*bad*)
2. Cubic Polynomial (*bad*)
3. Cubic Spline
4. Fourier Transform
5. Optimized filter (4-Tap, etc.)

Most commercial software packages have optimized interpolants for use!



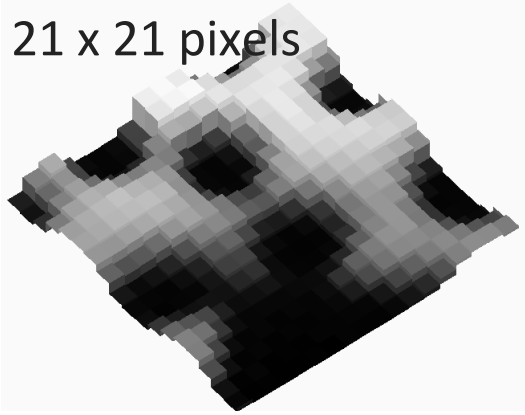
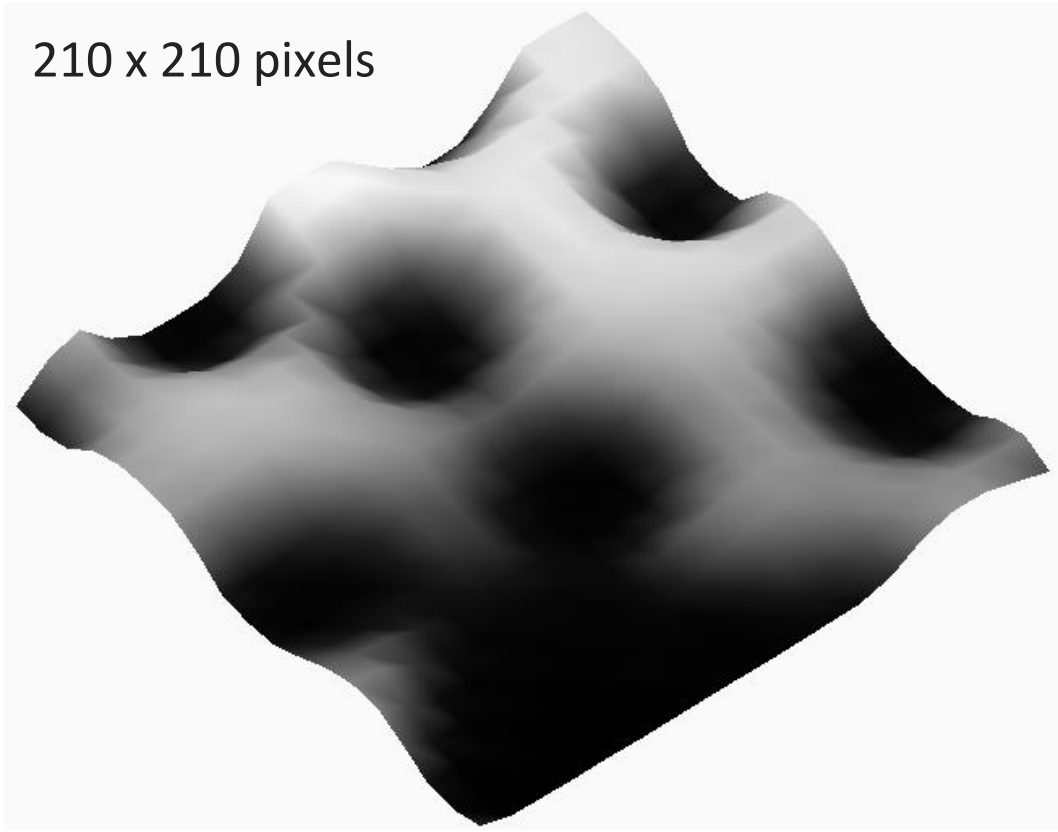


Image interpolated by a factor of 10x

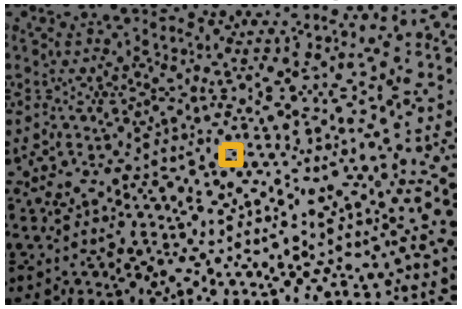


PL Reu (2012) "The Art and Application of DIC", *Exp Tech*, 36:3-4

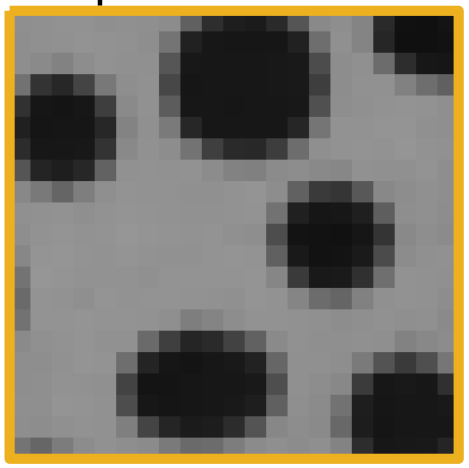
Correlation example: Interpolant

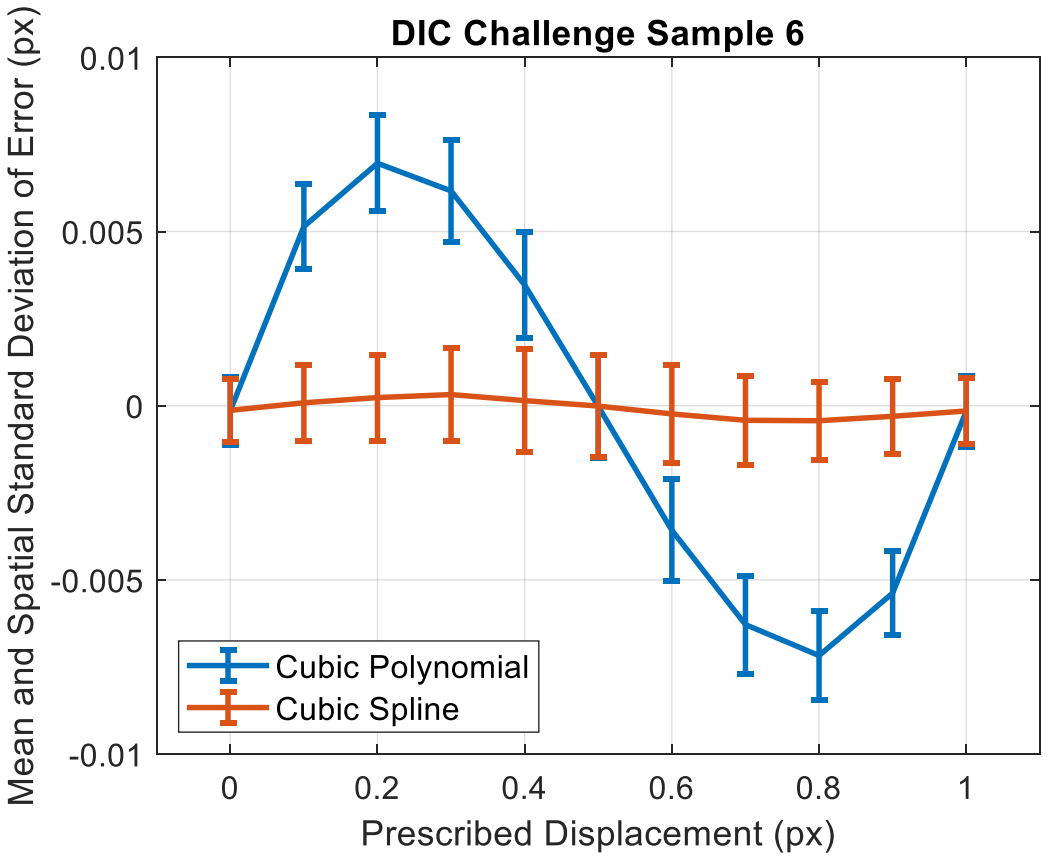
- ***DIC Challenge Sample 6***
  - Subpixel translation in x and y

Reference Image



Representative Subset





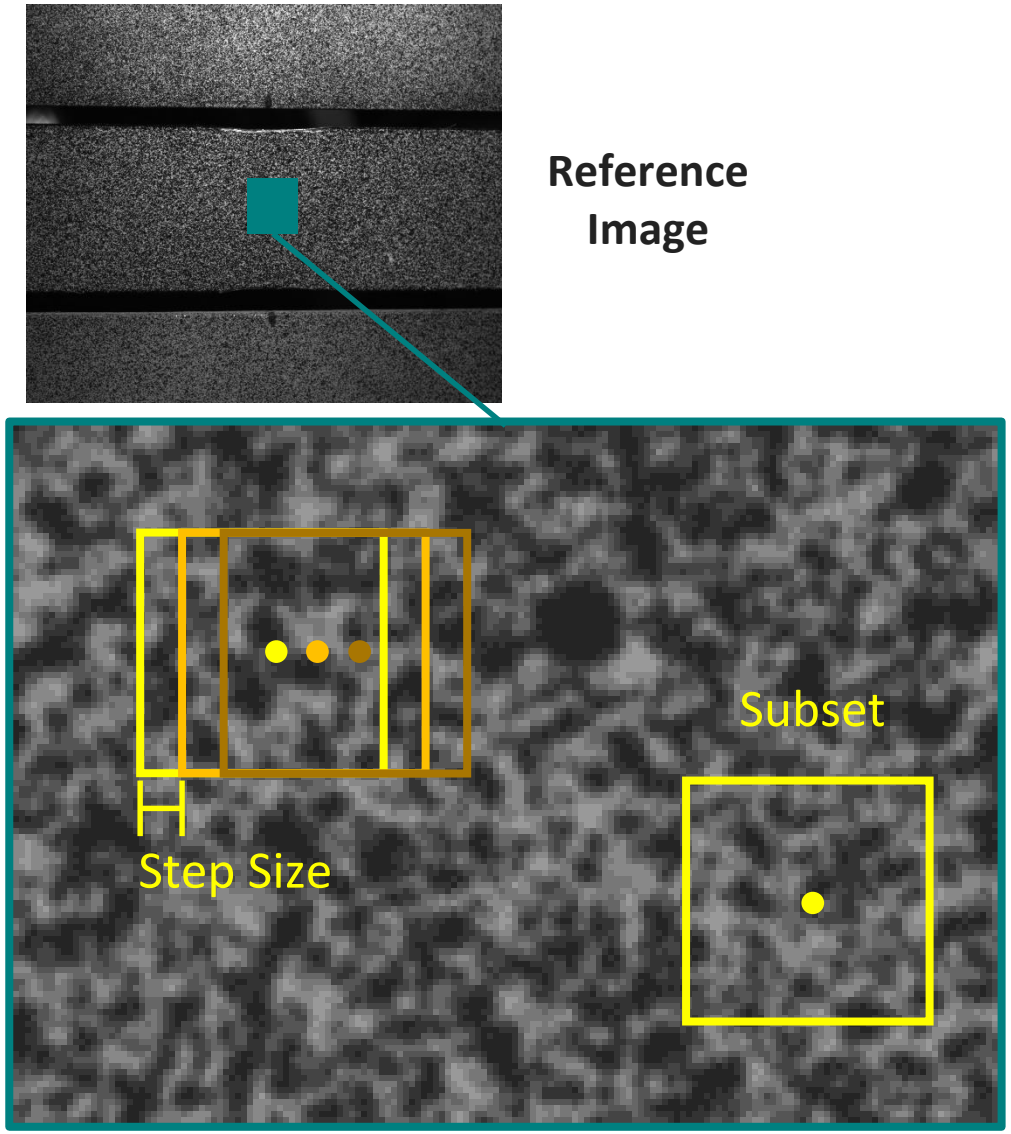
- *Correlation parameters*
  - Gaussian image prefilter with kernel size 5 px
  - Affine shape function
  - Single reference image
  - Subset size 21
  - Step size 5 (5590 points total)

The bi-cubic spline has much less bias than the bi-cubic polynomial.

Use these images to evaluate interpolants in your software.

Subset Size and Step Size
Sec. 5.2.5-5.2.6

- **Subset**: Portion of image used to calculate one 3D coordinate or displacement value
- **Subset Size**: Length of the subset in the reference image
- **Rules of thumb**:
  1. Subset should contain a minimum of 3 DIC pattern features that are each 3-5 pixels in size
  2. Subset size should be large enough to allow "adequate correlation" for all images in the test series
  3. Subset size should be large enough to minimize correlation error metric
- **Step Size**: Spacing at which subset displacements are calculated
- **Rules of thumb:**
  - 1/3 to 1/2 of the subset size is recommended
  - May need smaller step size to capture peaks

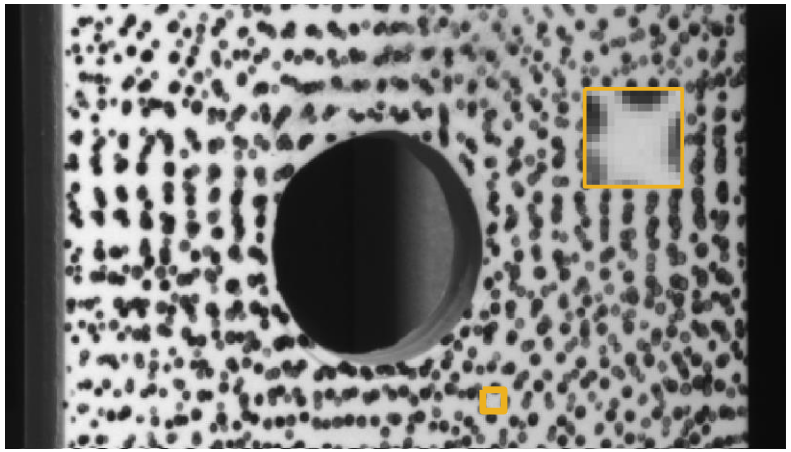


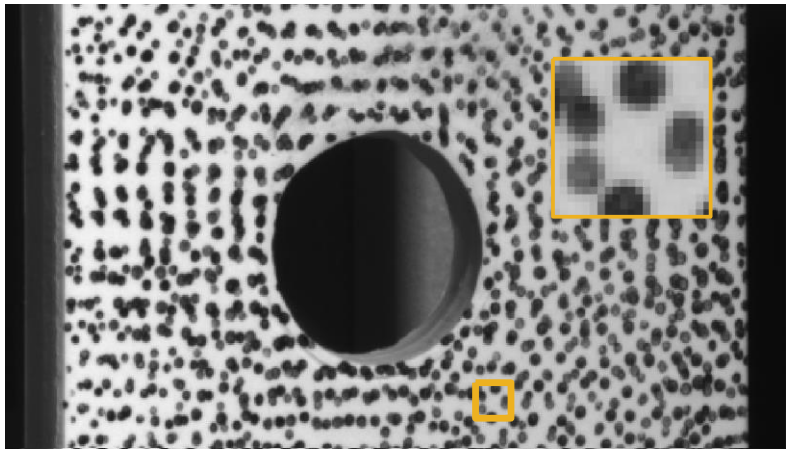
Correlation example: Subset

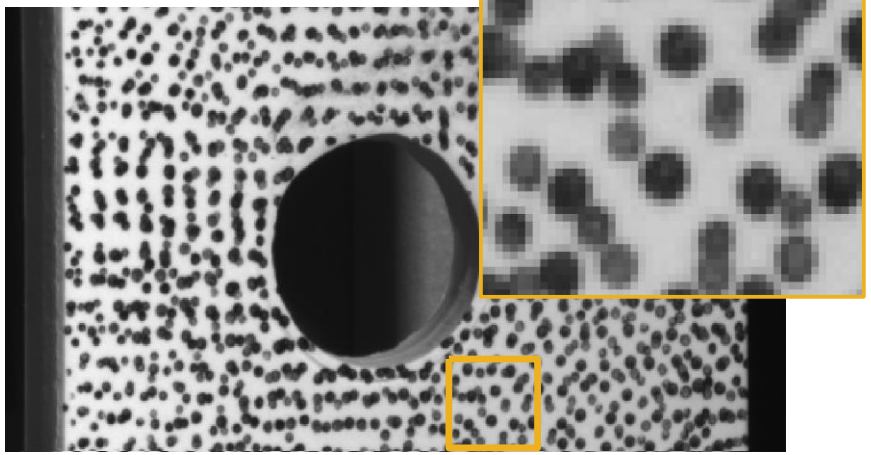
Subset size = 13 px
- Too small
- Insufficient number of features
- High correlation residual
- Many uncorrelated points

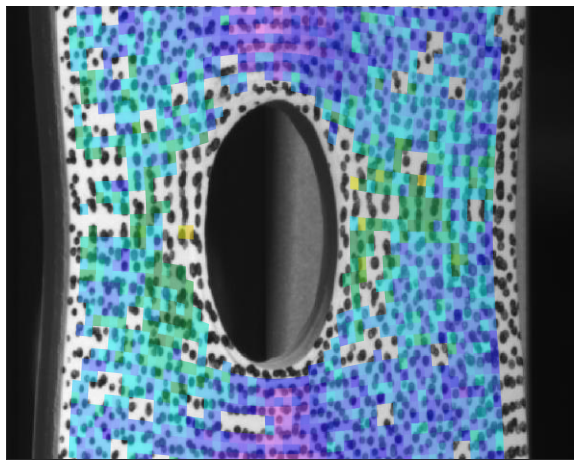
Subset size = 21 px
- Reasonable size
- Sufficient number of features
- Low correlation residual
- No uncorrelated points

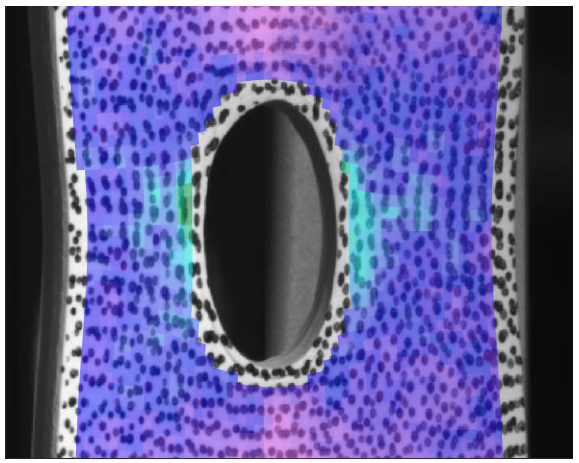
Subset size = 51 px
- Too large
- Large border of missing data near edges of ROI

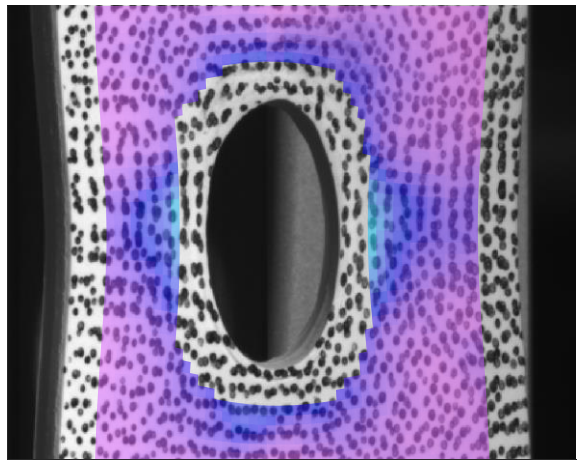




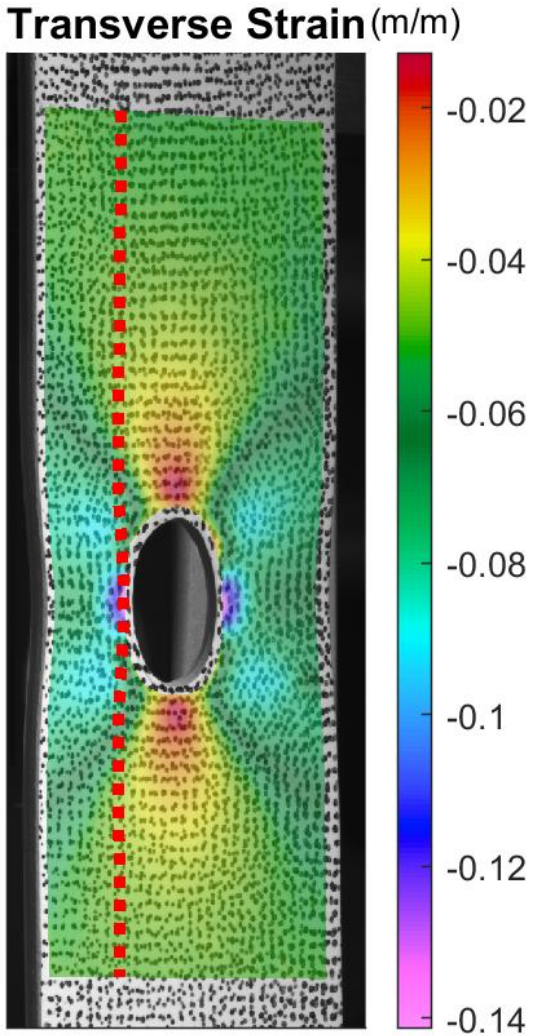


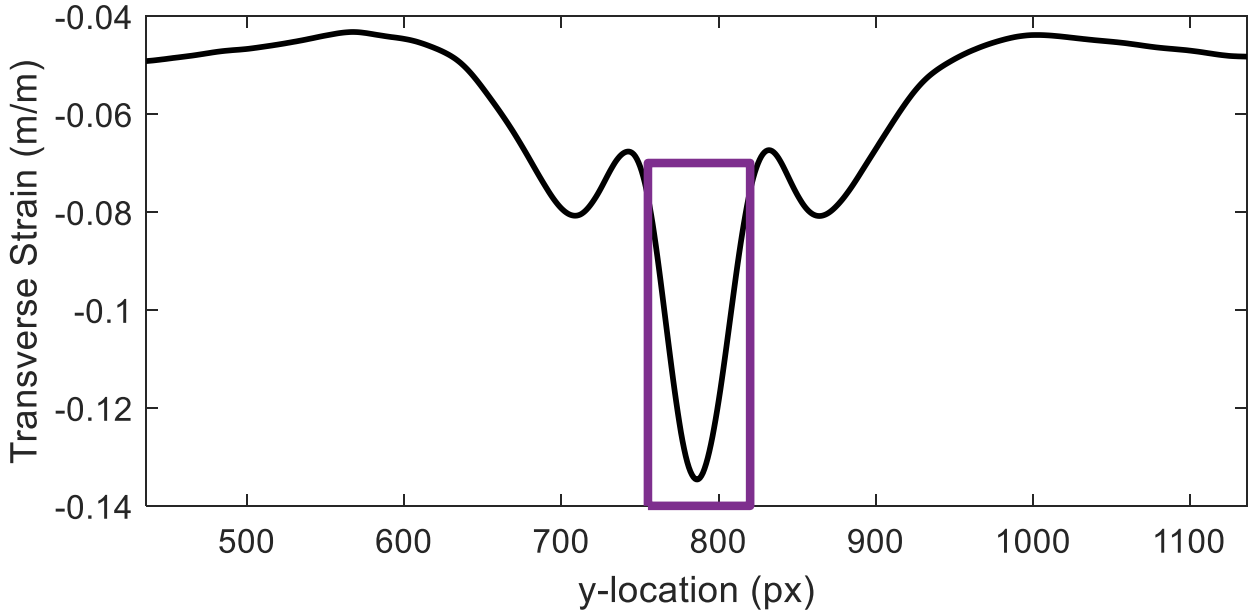


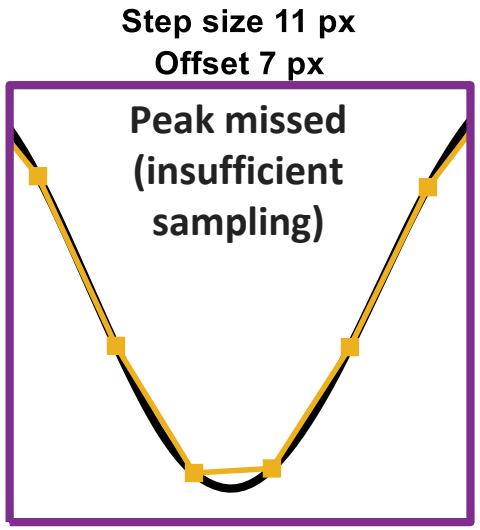


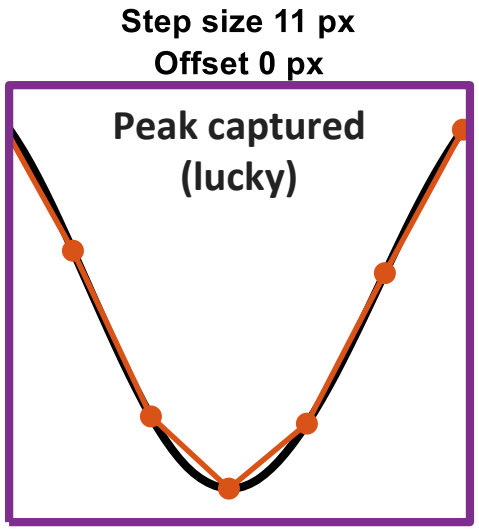


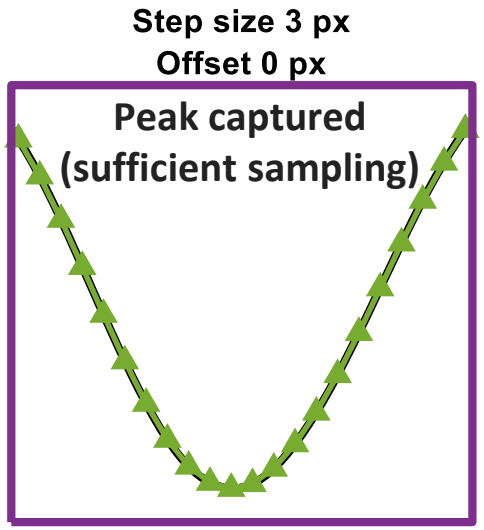
Correlation example: Step size











Thresholds
Sec. 5.2.7

- Determine the quality and confidence of the displacement results

- Two main thresholds
  - Value of the matching criterion
  - Value of the epipolar error

- Software dependent