SAND2019-6187C

Pattern Induced Bias in Digital Image Correlation

Samuel Fayad
Thomas Seidl,
Phillip Reu

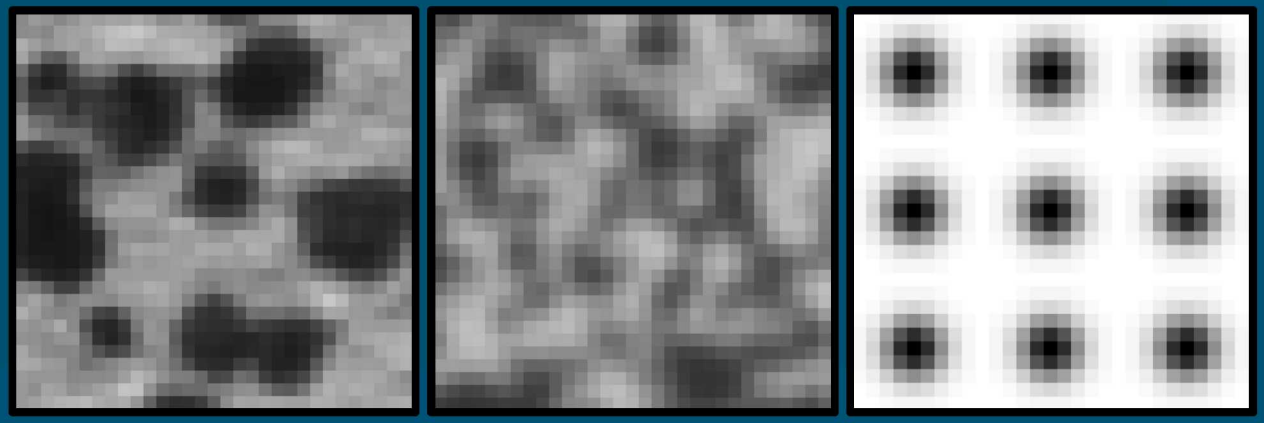
Additional team members:

Dr. Elizabeth Jones

Dr. Daniel Turner

Dr. Richard Lehoucq

John Miers



SEM 2019

Reno, NV

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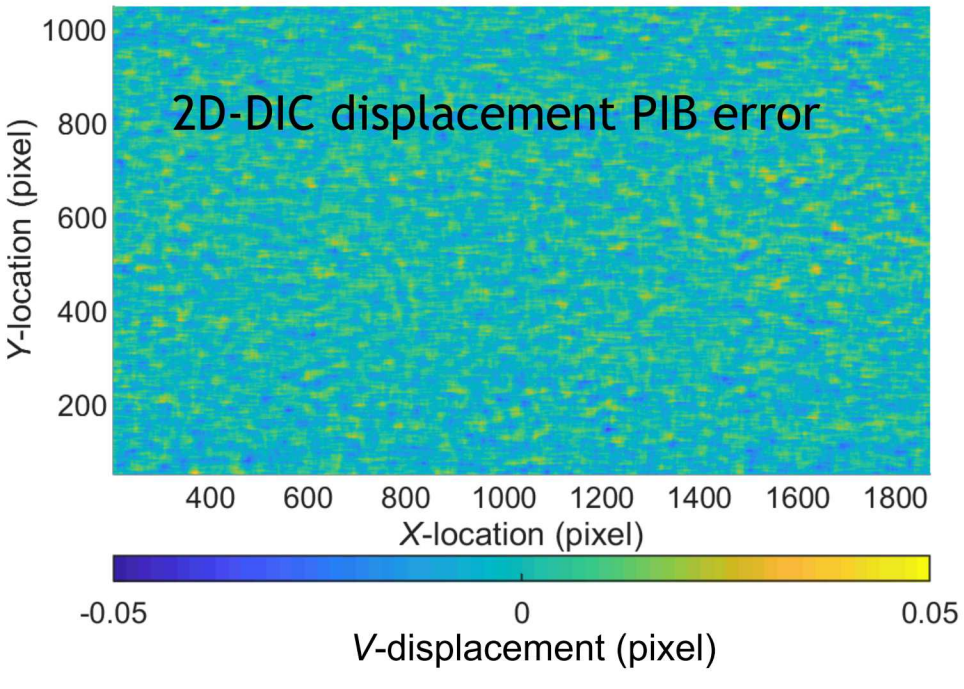
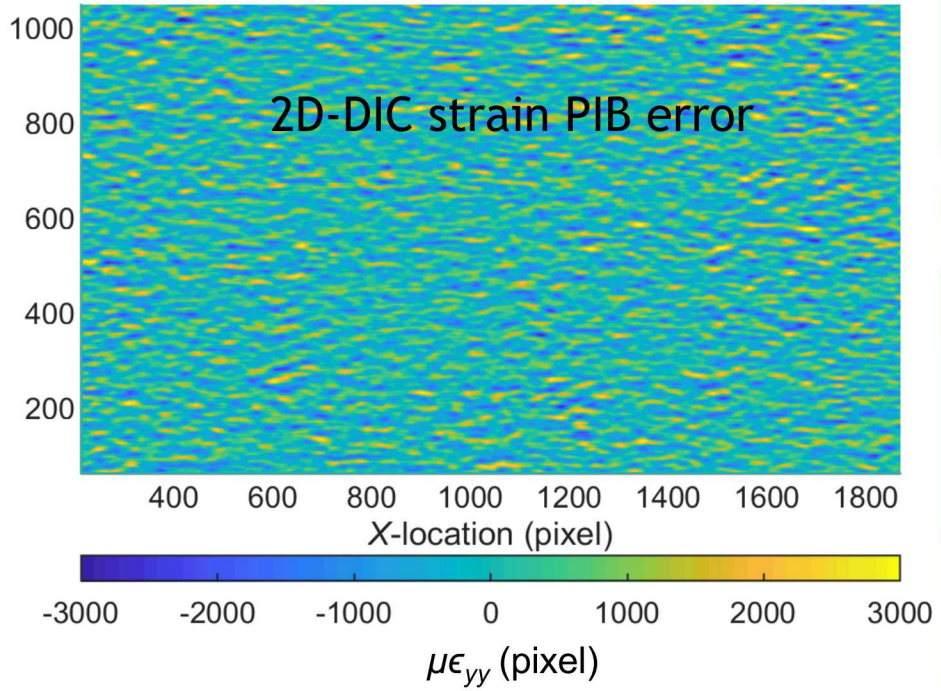
DIC has a spatial bias error caused by the interaction of the: Pattern, shape function and the deformation field.

Pattern Induced Bias (PIB) Error





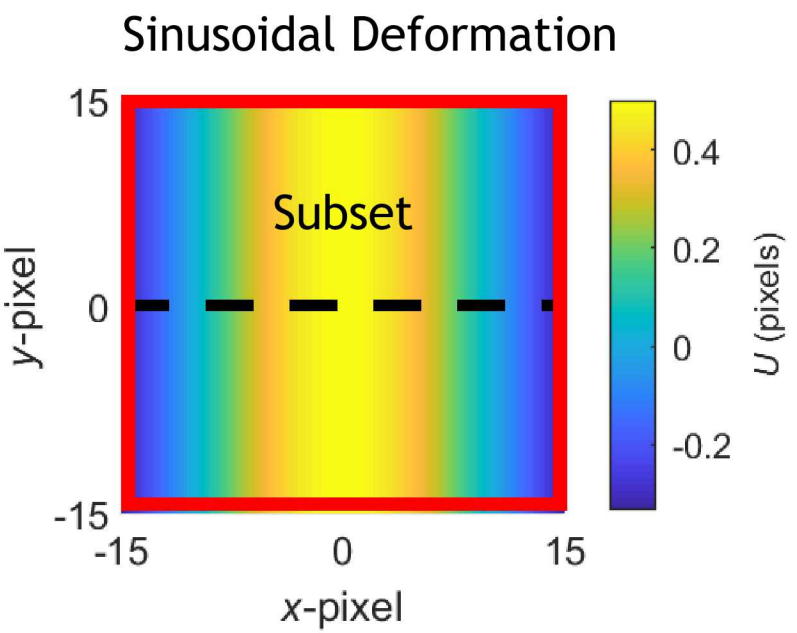
This term was briefly mentioned in literature[1] but has been largely ignored.

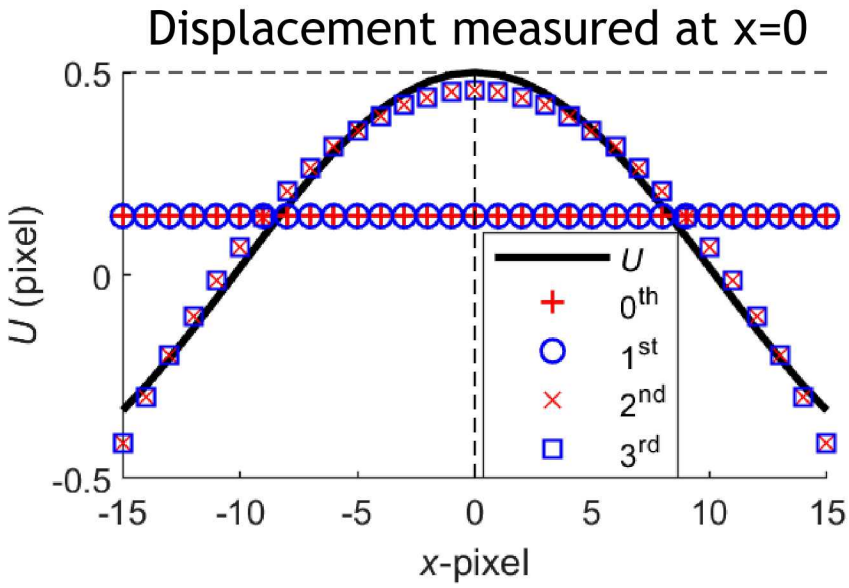
PIB can be larger than common terms such as lens distortion, heat haze, and temporal variance errors from vibration or image noise.

[1]Schreier, ExpMech, doi.org/10.1007/BF02410987

Undermatched shape functions can cause significant bias

The shape function is undermatched if it can't perfectly match the underlying deformation.



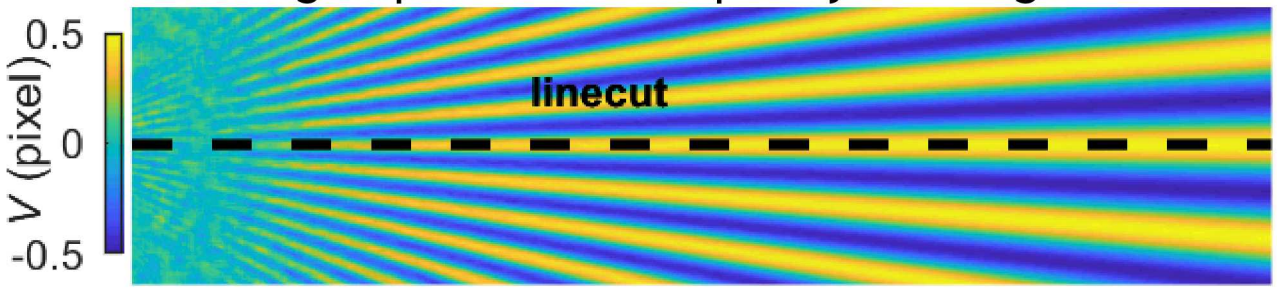


Deviation from true deformation (black line) is shape function attenuation bias

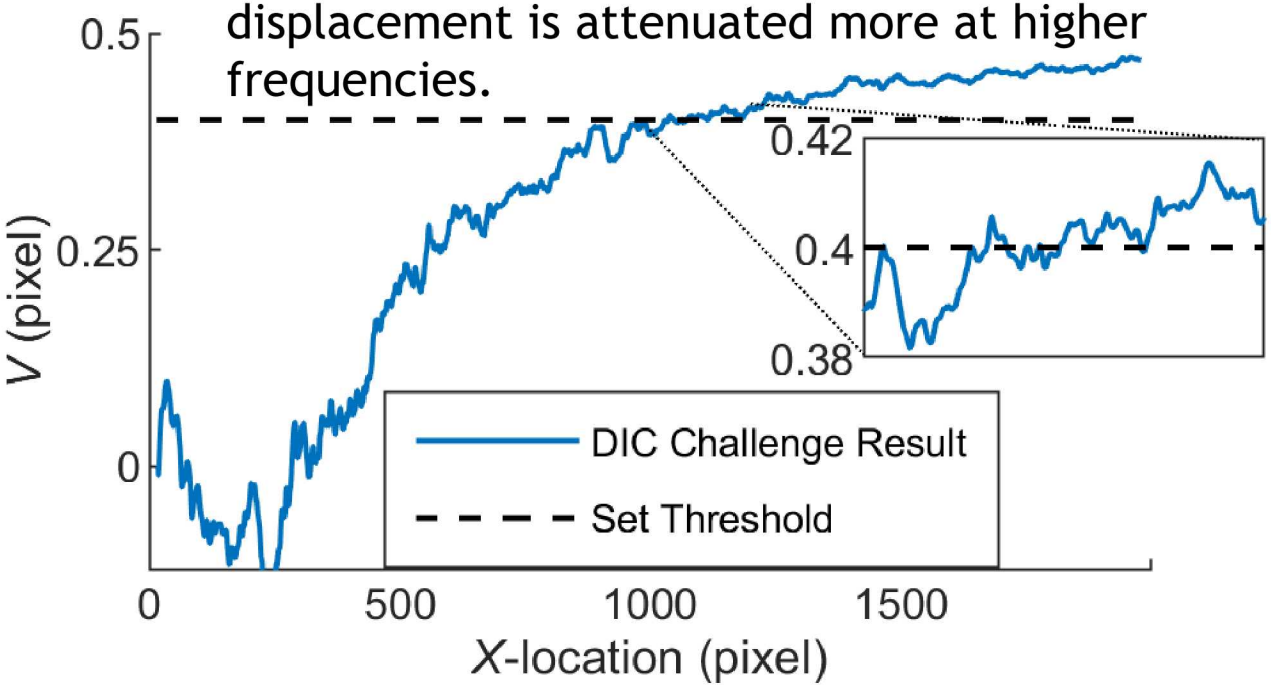
Shape function attenuation bias dictates the correlation results in the DIC Challenge 2.0 images.

Image Characteristics:

- Constant amplitude along the middle row
- Increasing displacement frequency from right to left



Due to shape function attenuation bias, the displacement is attenuated more at higher frequencies.

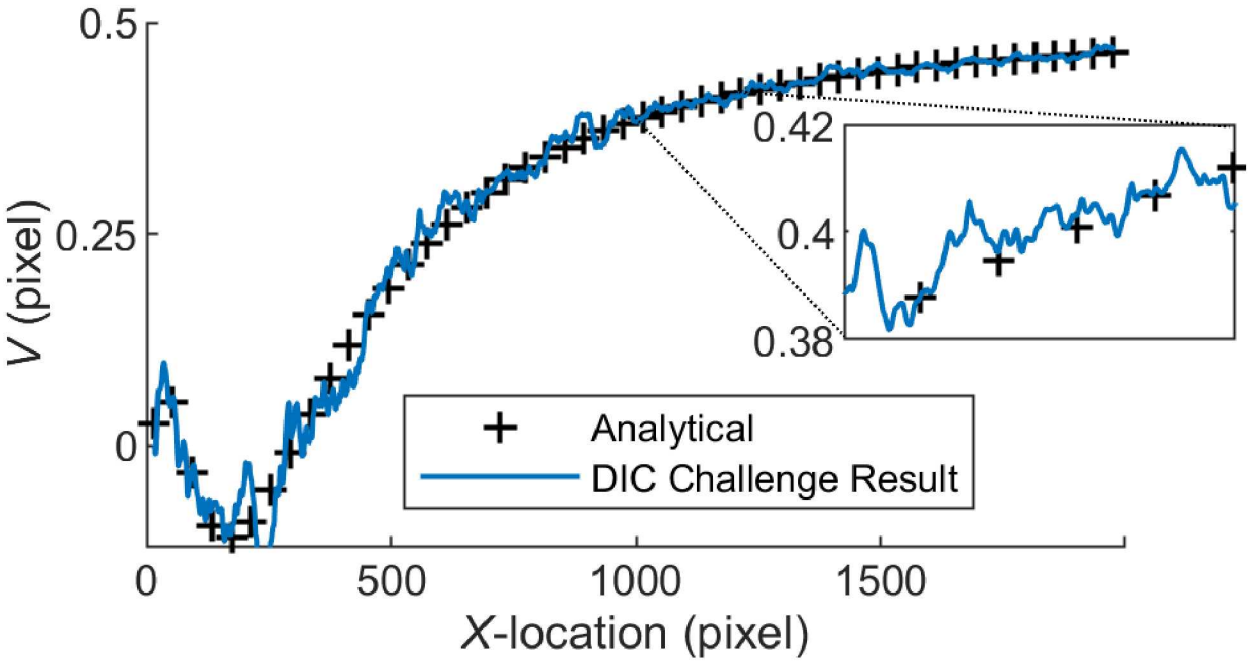


The DIC solution crosses the threshold multiple times, obfuscating the resolution limit.

The expected DIC results can be evaluated numerically and analytically.

Expected DIC Solution
(black crosses)

$$v(X_0) \cong \frac{1}{\Omega K(X_0)} sin\left(\frac{\Omega K(X_0)}{2}\right)$$



Unknown error causes the deviation of the blue line from the expected solution

Introducing image noise did not change the bias

Image number

1

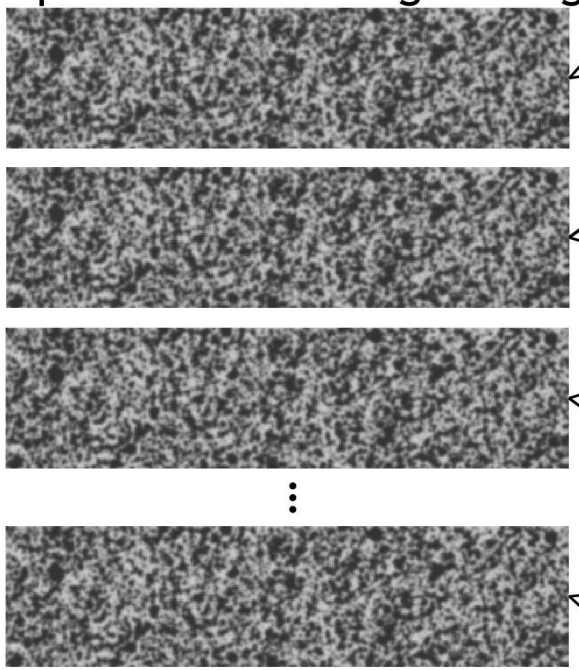
2

3

⋮

50

100 pixel x 400 pixel visual samples from the larger image

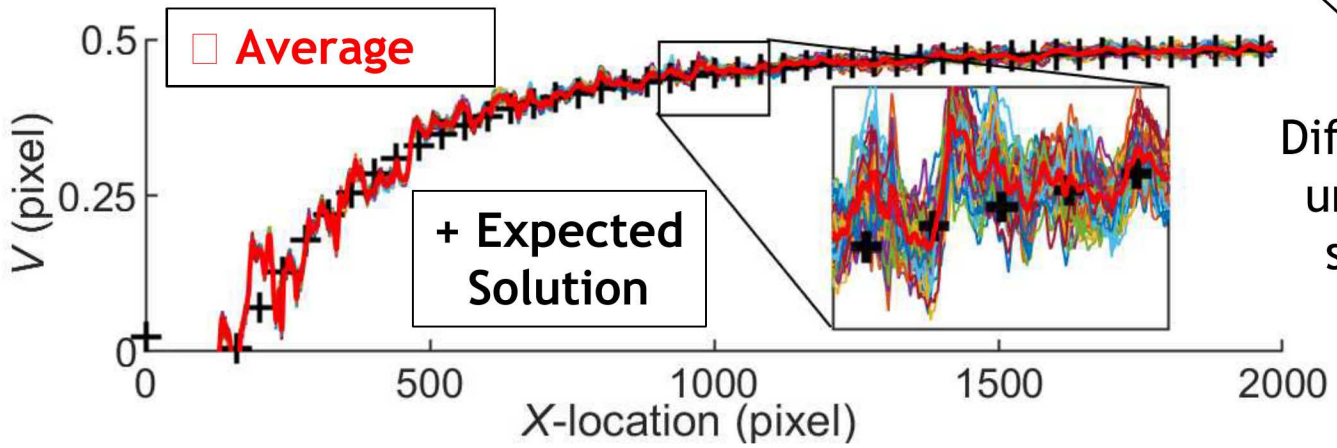


114	127	156
96	106	141
74	85	122

114	126	156
94	104	141
79	85	120

110	127	159
92	108	142
77	85	118

111	126	154
91	107	139
76	82	123



Different instances of unique noise didn't smooth the curve

Averaging unique patterns eliminated this error

Image number

100 pixel x 400 pixel samples from the larger image

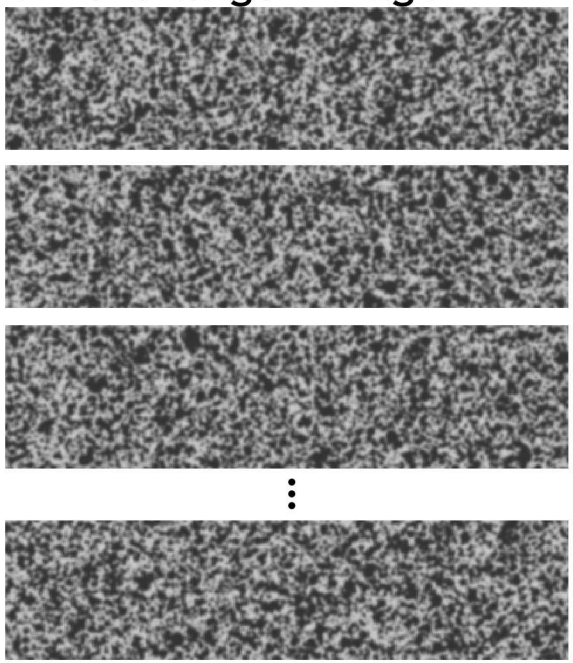
1

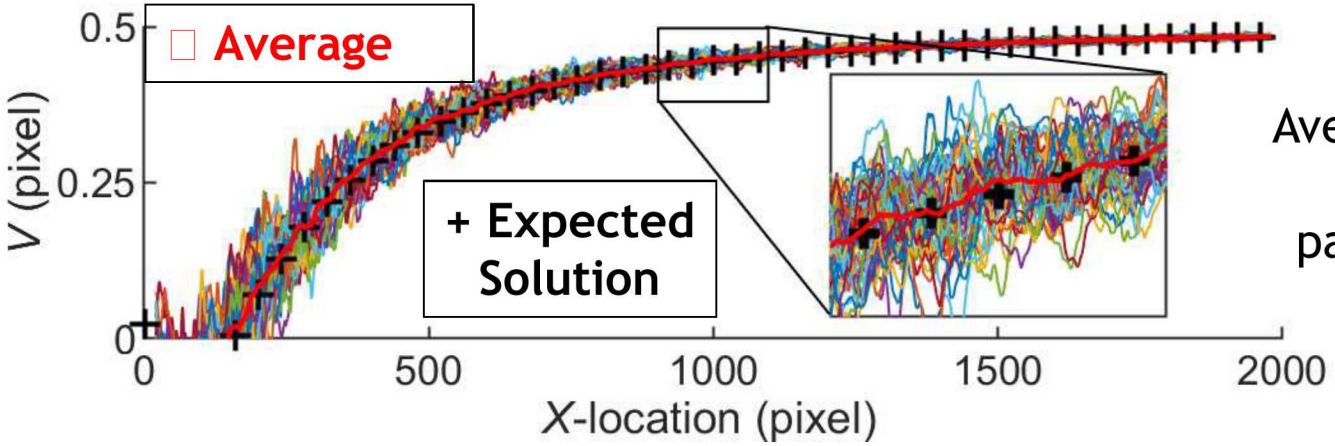
2

3

⋮

50

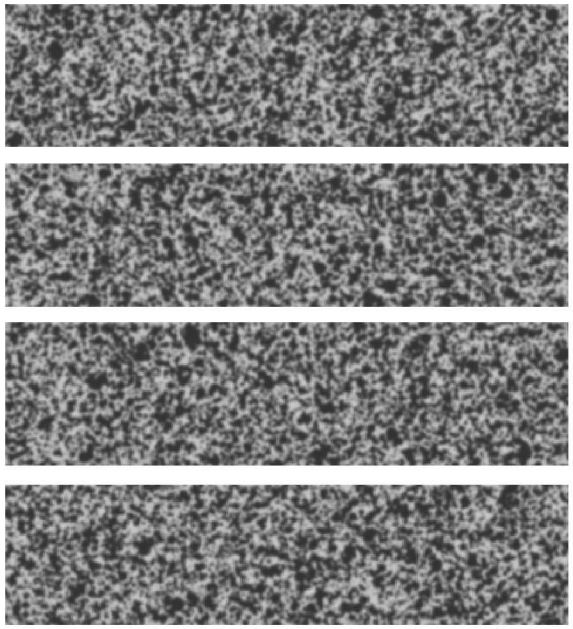




Averaging DIC results from different patterns smoothed the curve

Note: Similar results occur for strain

What was the cause of the bias?



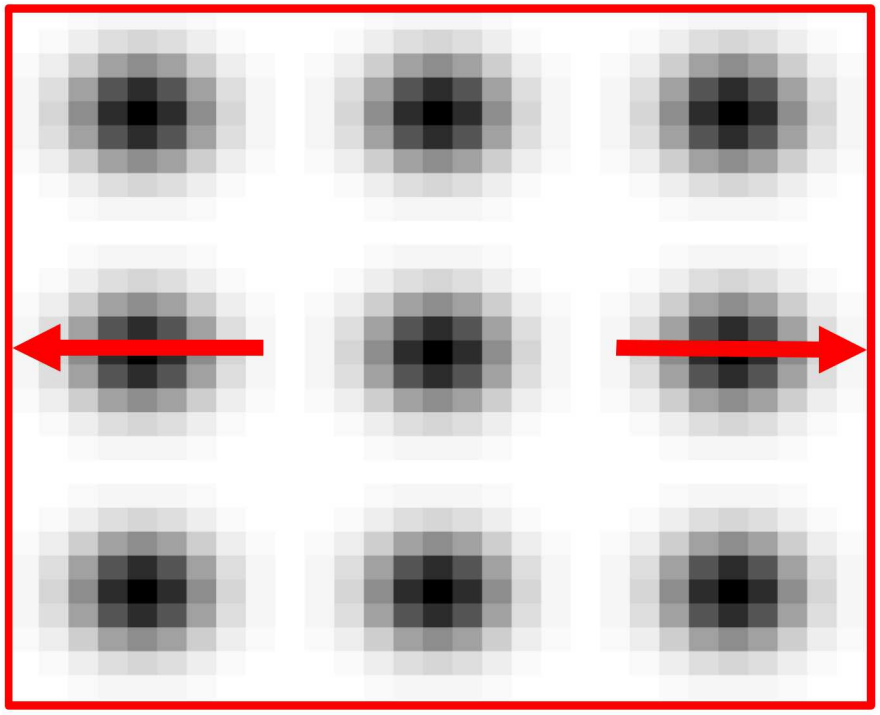
The error is influenced by the intensity pattern, hence Pattern Induced Bias (PIB)

This error only occurs in the presence of an undermatched shape function

The influence of the pattern was evaluated numerically using a double precision pattern

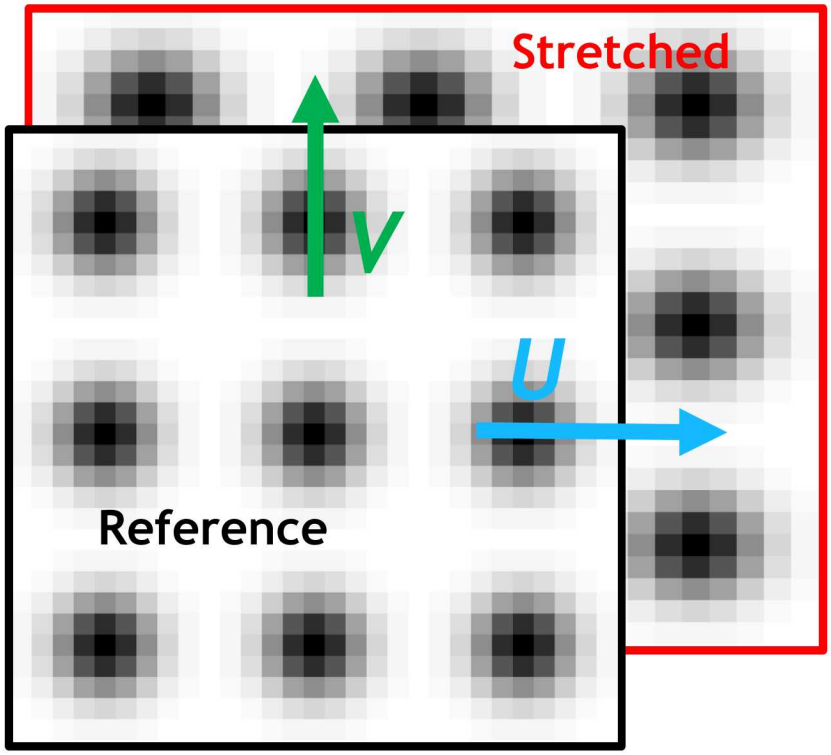
A continuous pattern sampled at 31 “pixels”

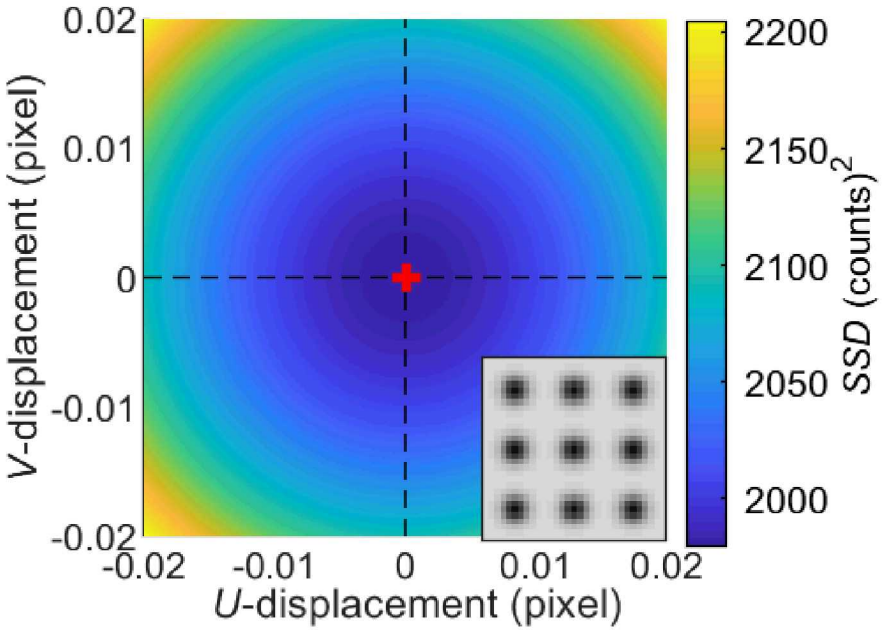
1% uniform horizontal stretch



DIC using a 0th order shape function can be simulated by rigidly shifting the reference pattern over the stretched pattern and evaluating the *SSD*.

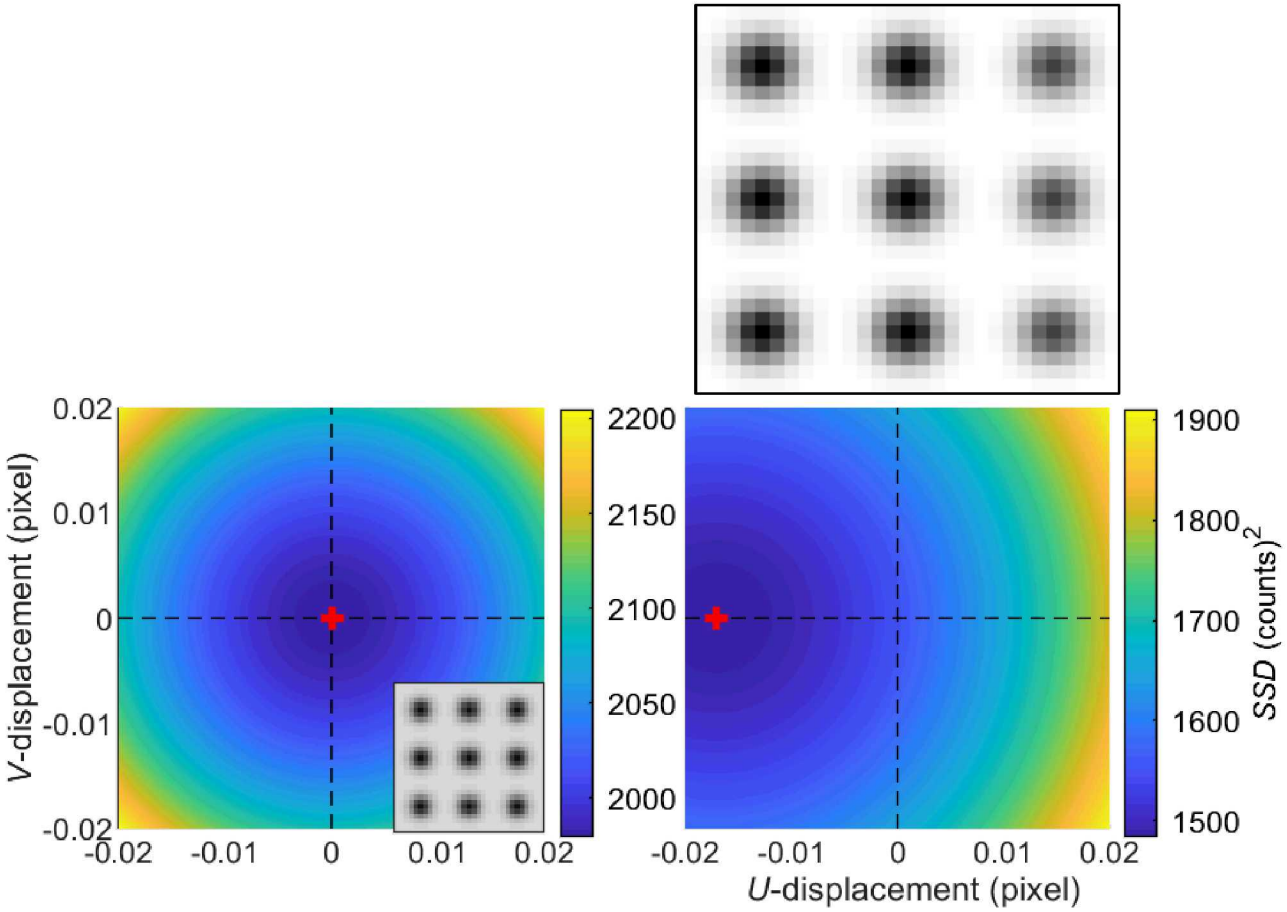
$$SSD \equiv \frac{1}{2}\sum_{x=-M}^{M}\sum_{y=-M}^{M} \boldsymbol{w}(\boldsymbol{x})\big(I(\boldsymbol{x}) - G(\boldsymbol{x}+\boldsymbol{U})\big)^2$$





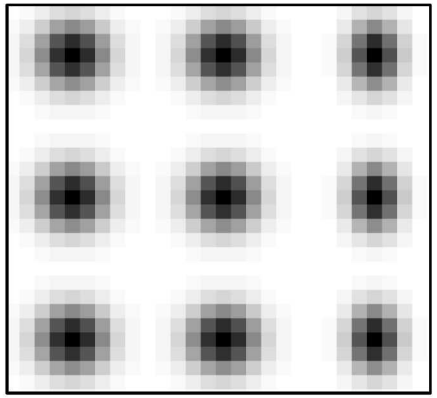
The perfectly symmetric pattern is an unlikely case

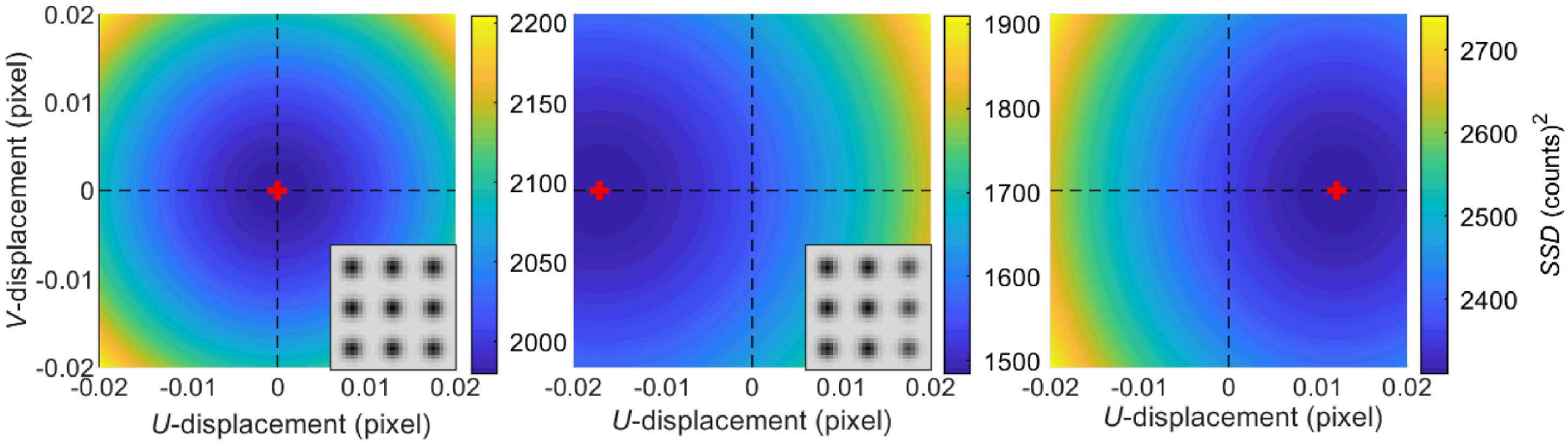
PIB is influenced by the characteristics of the features within a pattern such as contrast, gradient, geometry, position,…



PIB is influenced by the characteristics of the features within a pattern such as contrast, gradient, geometry, position,…

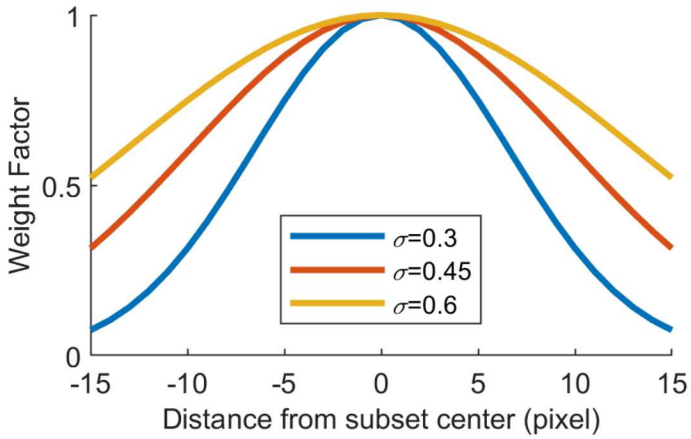
- The DIC solution is biased by higher contrast features.

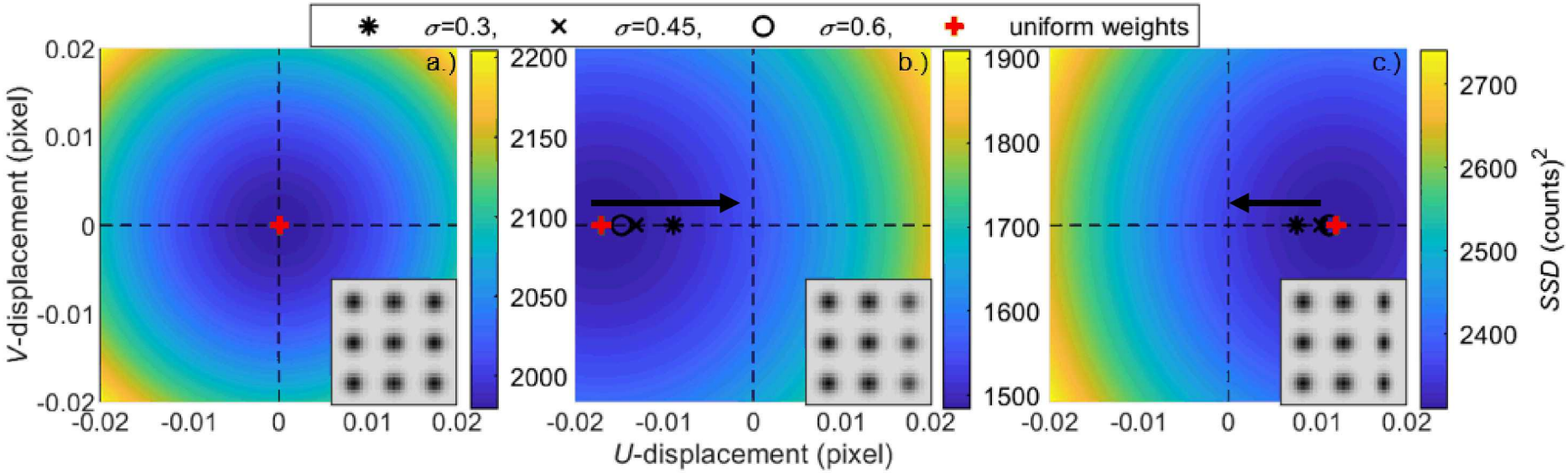




PIB is influenced by the characteristics of the features within a pattern such as contrast, gradient, geometry, position,…

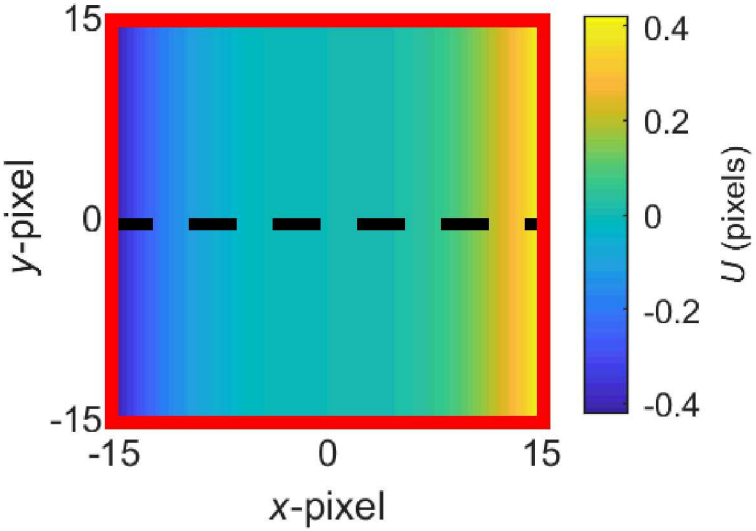
- The DIC solution is biased by higher contrast features.
- The DIC solution is biased by sharper gradients
- Center weighting reduces this error





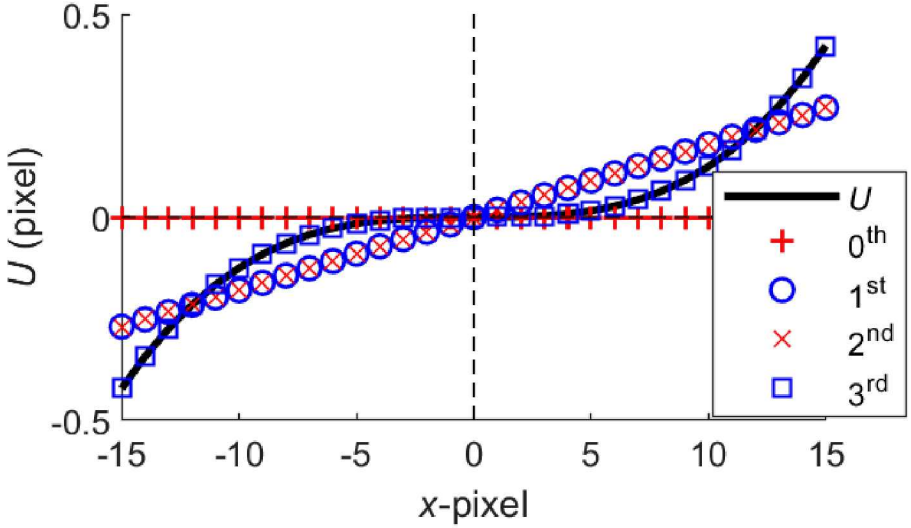
Antisymmetric deformations are undermatched, but don't produce shape function attenuation bias

Cubically deformed pattern



Lower Contrast

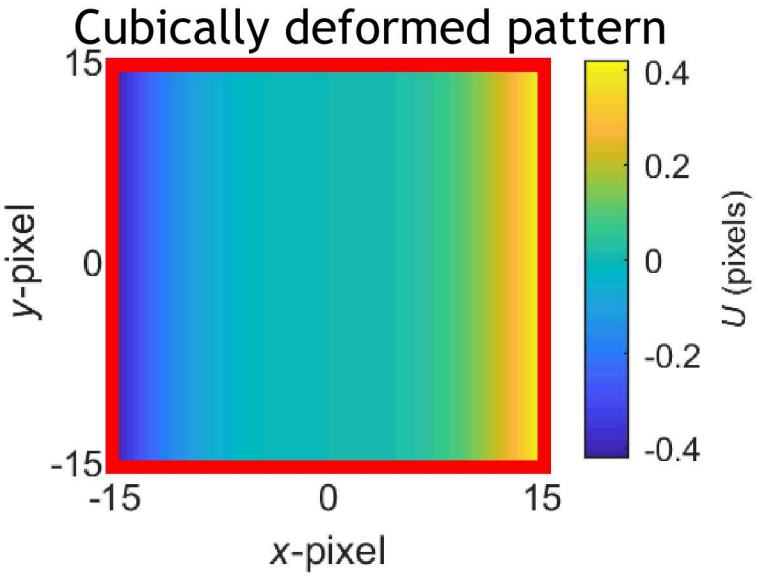
No Bias

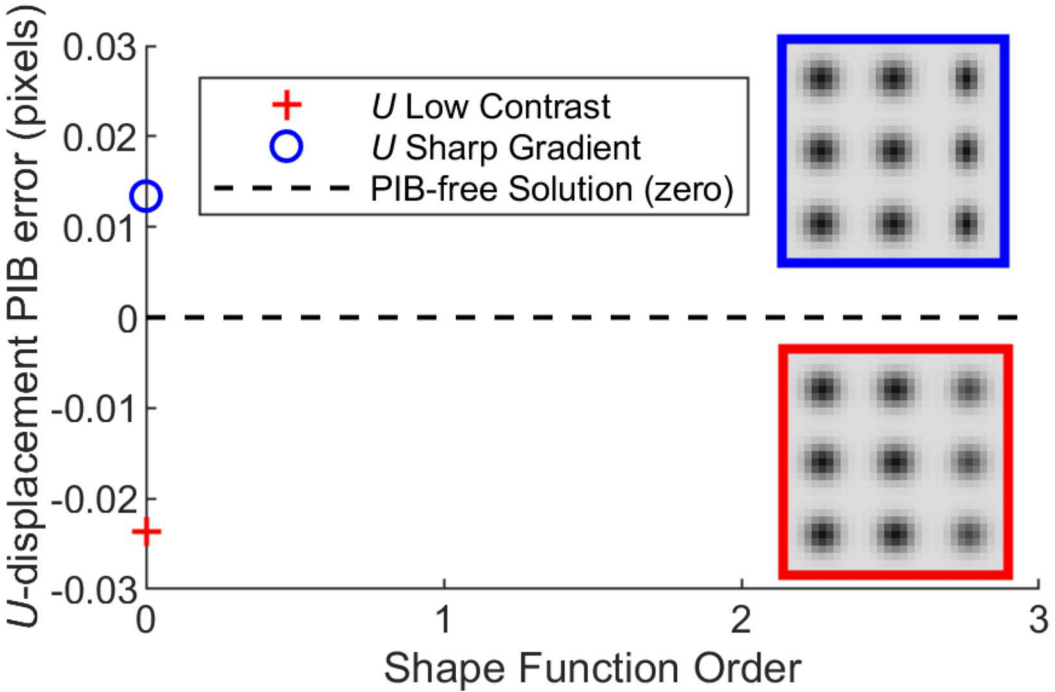


Higher Gradient

Magnitude and direction of PIB evolves with choice in shape function

- The 0th order shape produces large PIB error

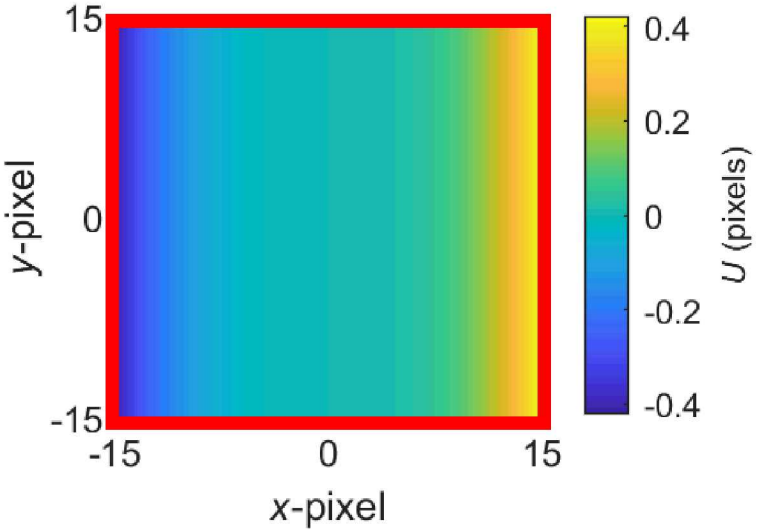


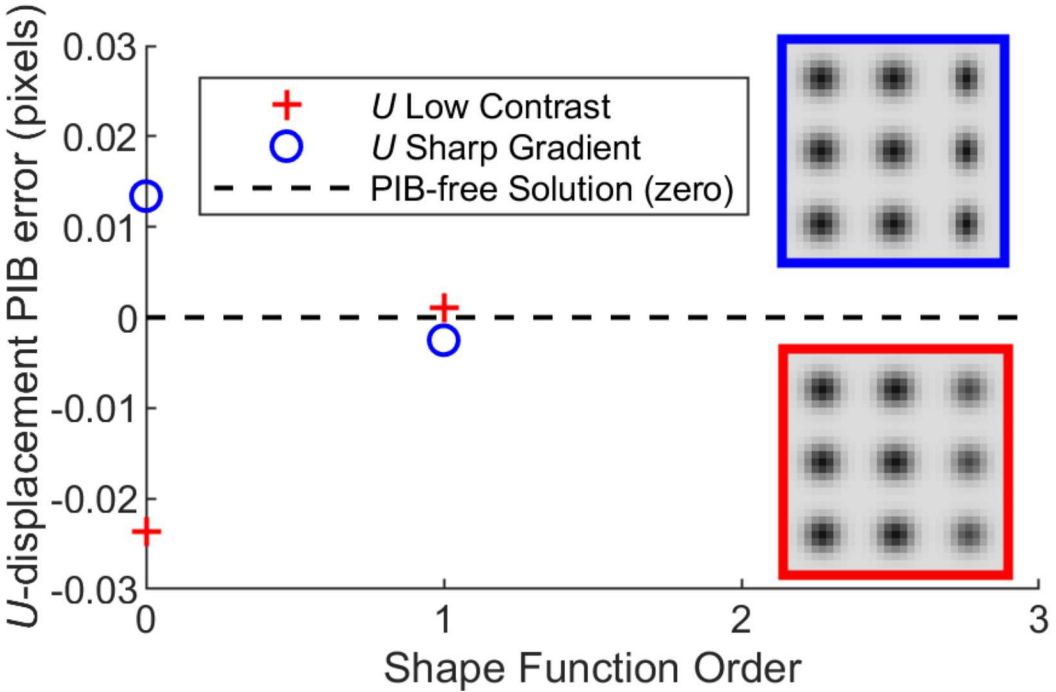


Magnitude and direction of PIB evolves with choice in shape function

- The 0th order shape produces large PIB error

- The 1st order shape function better approximates the displacement.



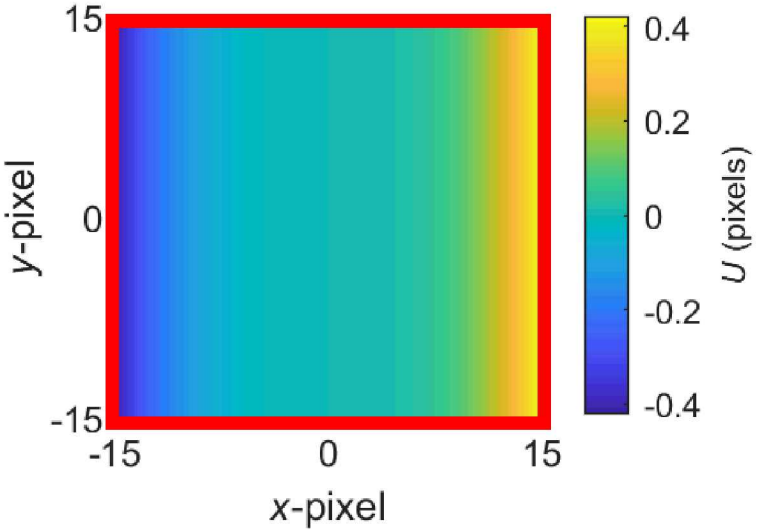


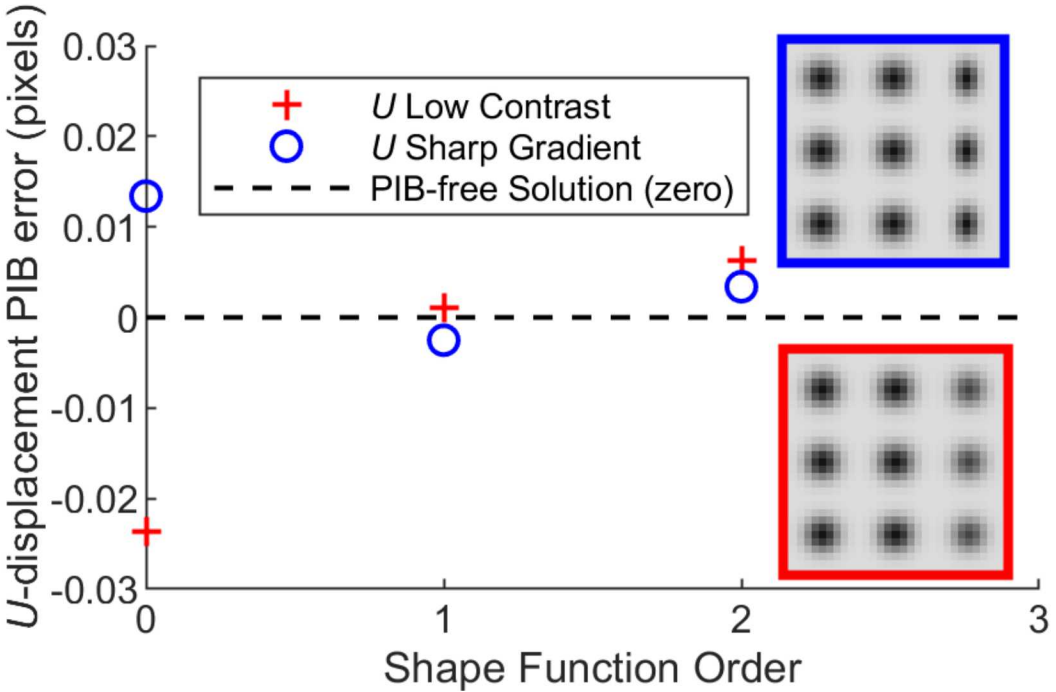
Magnitude and direction of PIB evolves with choice in shape function

- The 0th order shape produces large PIB error

- The 1st order shape function better approximates the displacement.

- The quadratic parameter in the 2nd order shape function further biases the results to minimize the SSD.





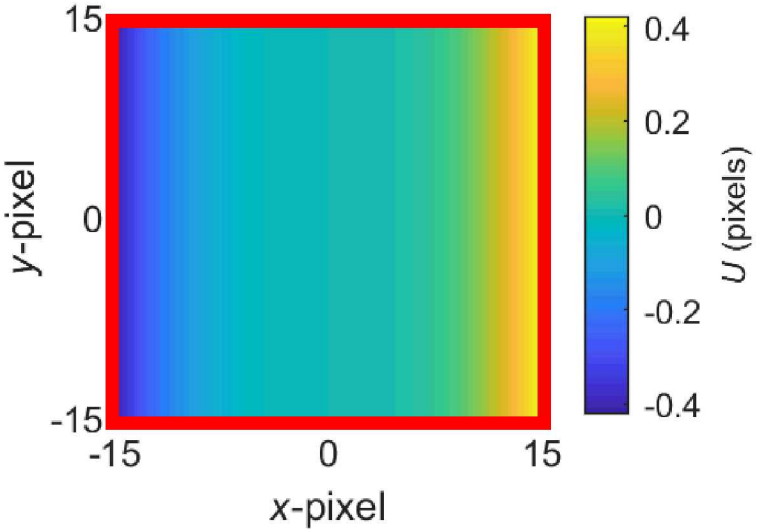
Magnitude and direction of PIB evolves with choice in shape function

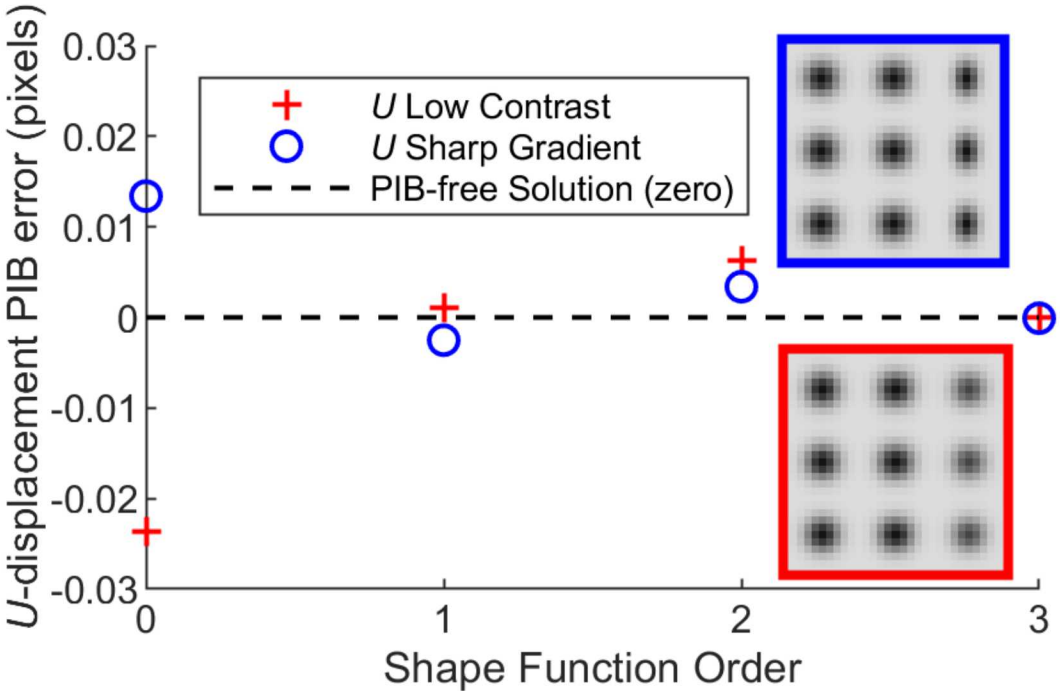
- The 0th order shape produces large PIB error

- The 1st order shape function better approximates the displacement.

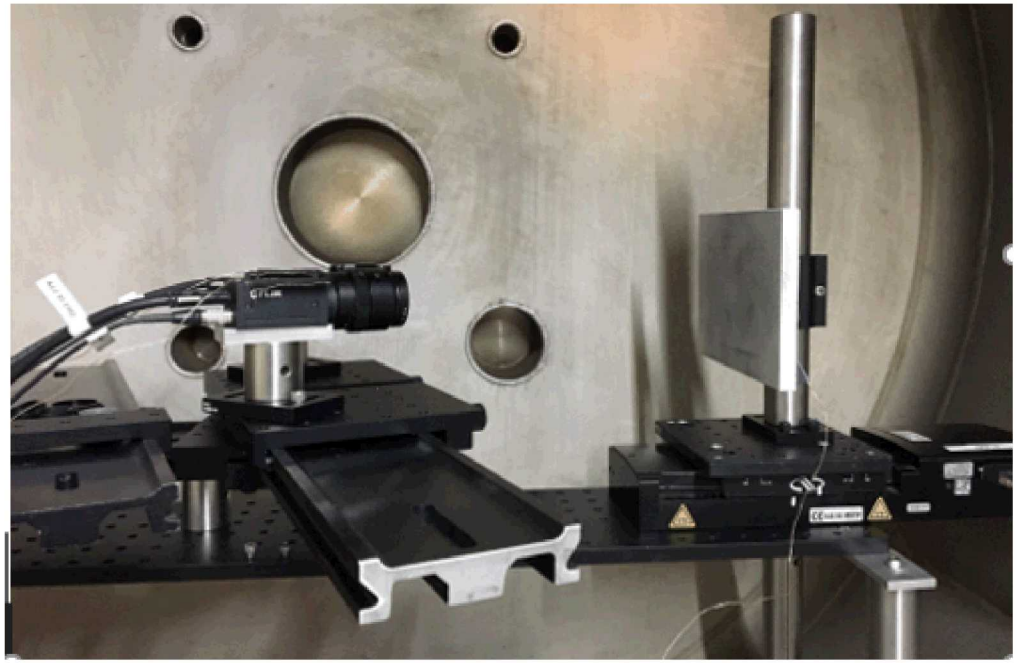
- The quadratic parameter in the 2nd order shape function further biases the results to minimize the SSD.

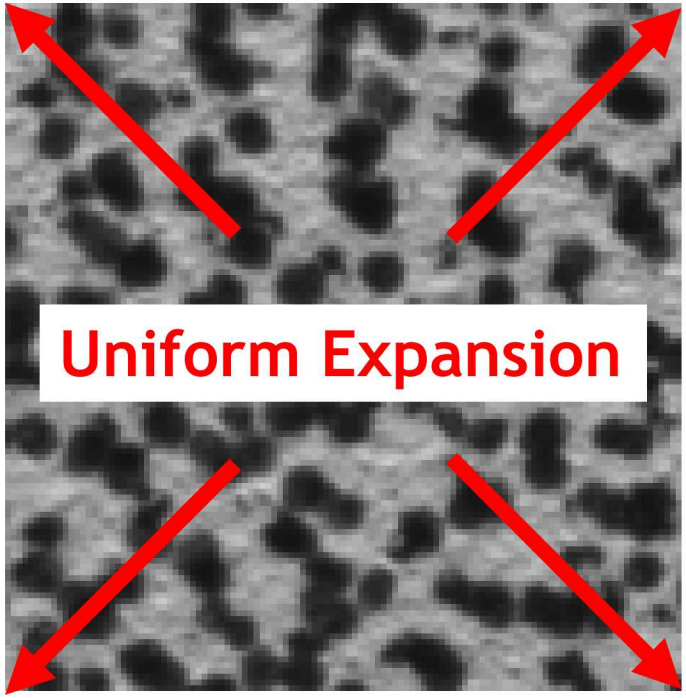
- The 3rd order shape function is not undermatched, no PIB error





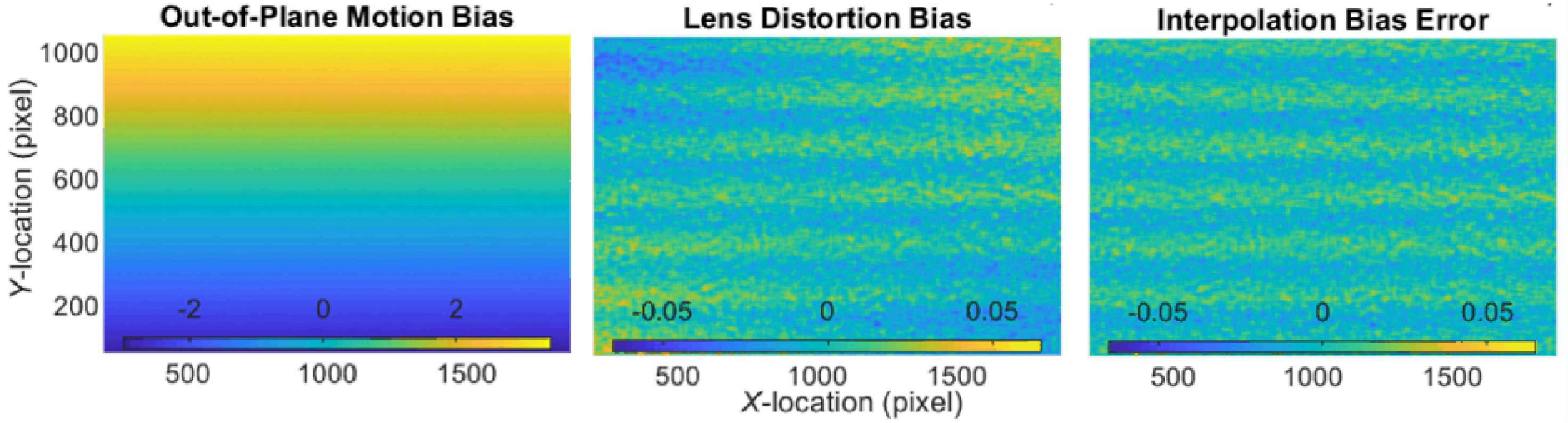
PIB error is demonstrated in a simple out-of-plane motion experiment.

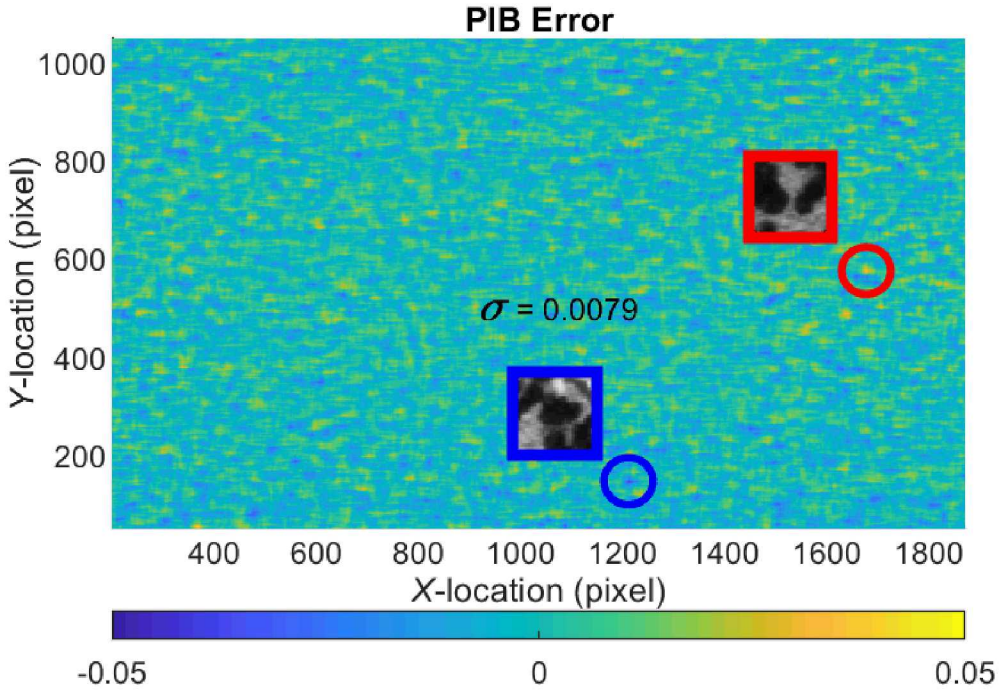


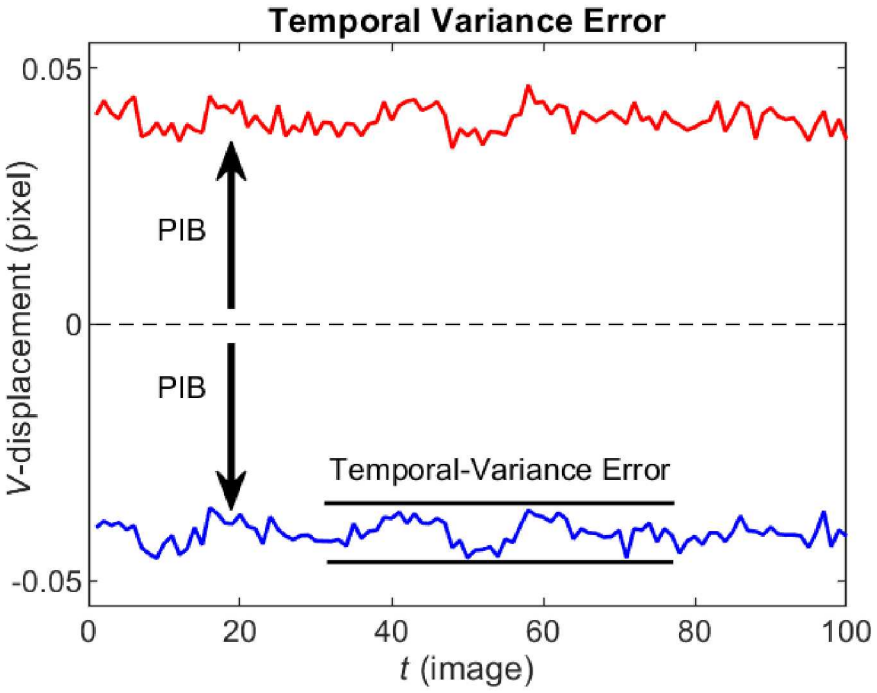


- Stereo set-up for 3D DIC, Orthogonal camera for 2D DIC
- A floating vacuum chamber was used to prevent vibrations and index of refraction changes in the air (largest error source).
- Out-of-plane motion used to create a perfectly uniform expansion (largest 2D error source)
- Experimental images were averaged to remove the temporal-variance error

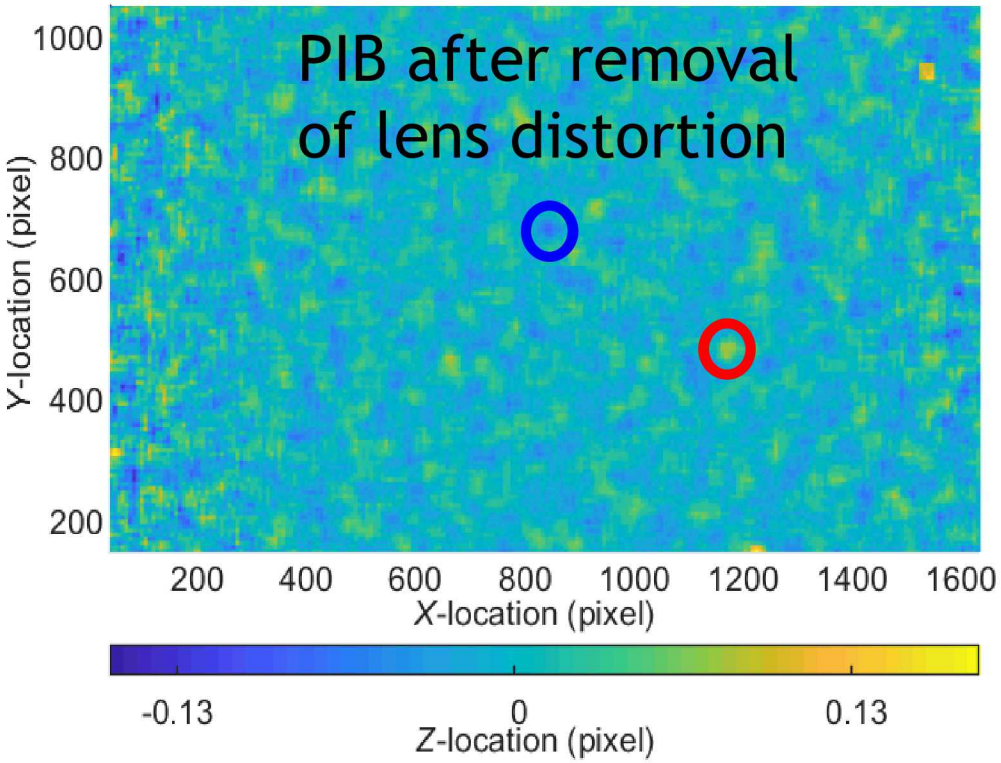
The PIB error is the 2nd or 3rd most important DIC error.



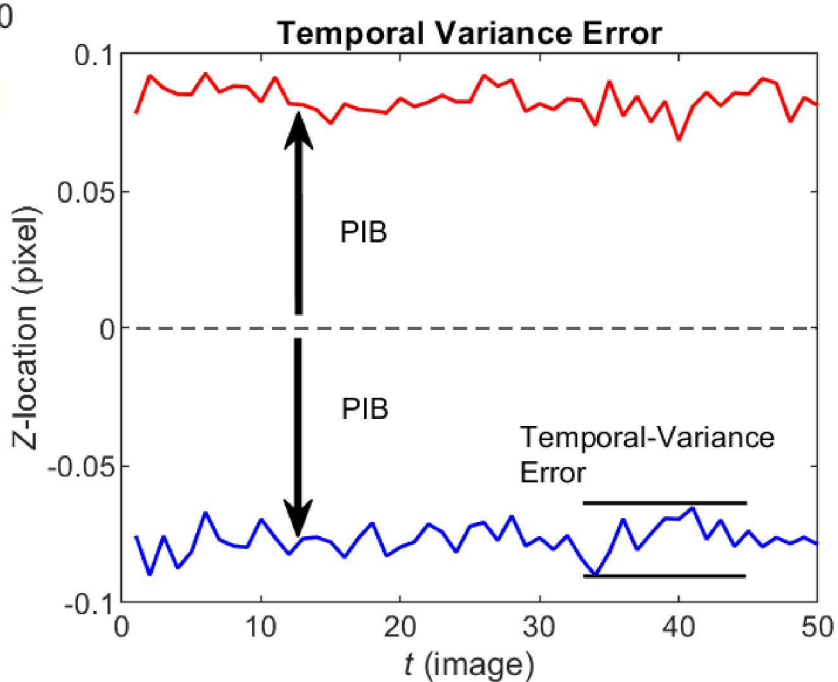




PIB exists in Stereo-DIC

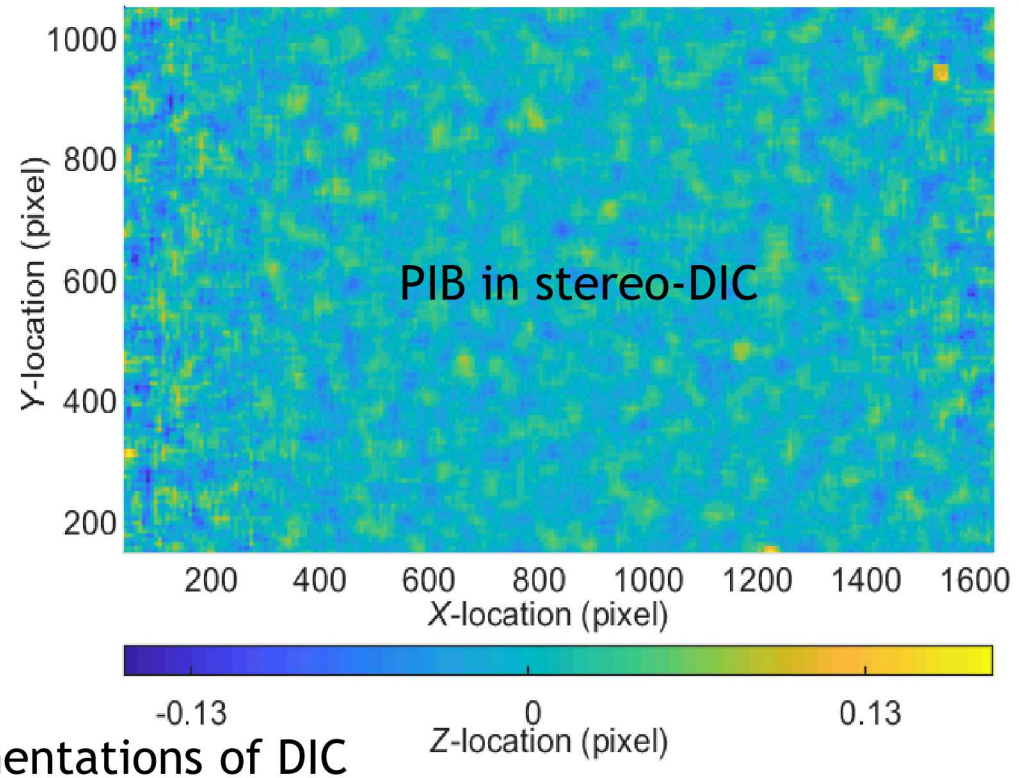


Again, the error is spatially variant, but not temporally variant



Conclusions

- PIB results in a spatial bias error
- PIB is not temporally-variant
- PIB is dependent on the pattern
- Subset weighting improves this error
- PIB exists only when the shape function is undermatched and varies with choice of shape function



- Lastly, PIB occurs for all implementations of DIC due to the ubiquity of intensity patterns and undermatched shape functions.