Computer Vision Approach to Study Surface Deformation of Materials

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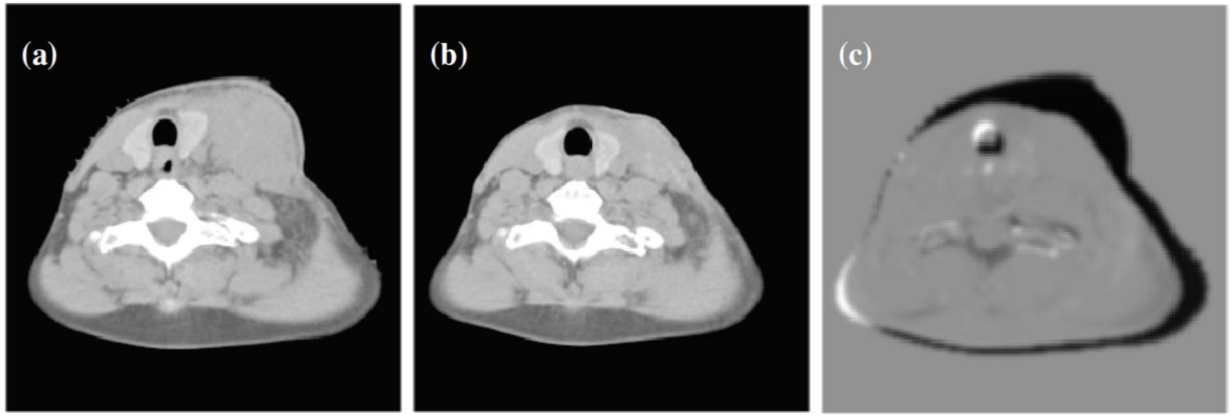
Technical Meeting and Exhibtion
MS&T20
MATERIALS SCIENCE & TECHNOLOGY

Motivation

Image Registration

Effect of radiation treatment on tumor near neck region



Before treatment — After treatment — Difference

Wang et al., 2005

1. Can we use it to map strain?
2. How accurate can this be?

Digital Image Correlation

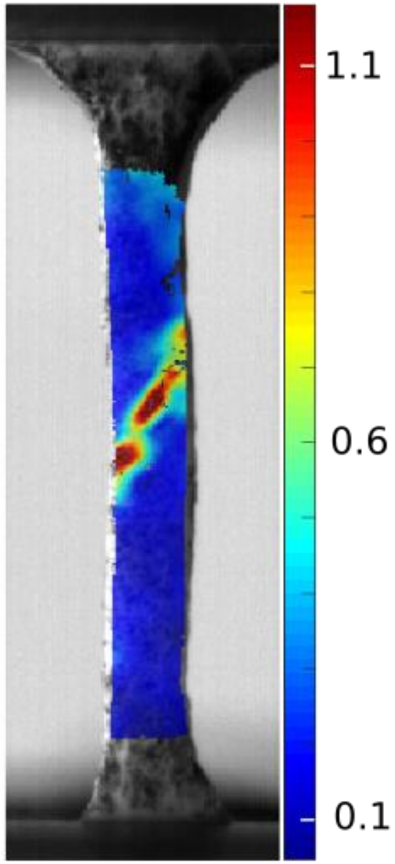
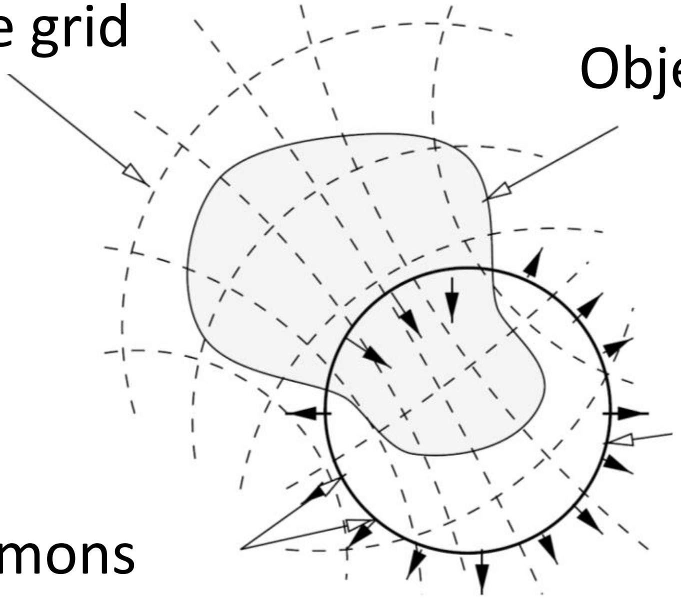


Image-to-Image Matching: The Diffusing Model

Deformable grid

Object in the moving image (M)



Fixed image (F) with semi-permeable boundaries

demons

The moving image (M) on a deformable grid diffuses through the semi-permeable boundaries (static contours) of the fixed image (F) by the action of effectors (demons) along the boundaries.

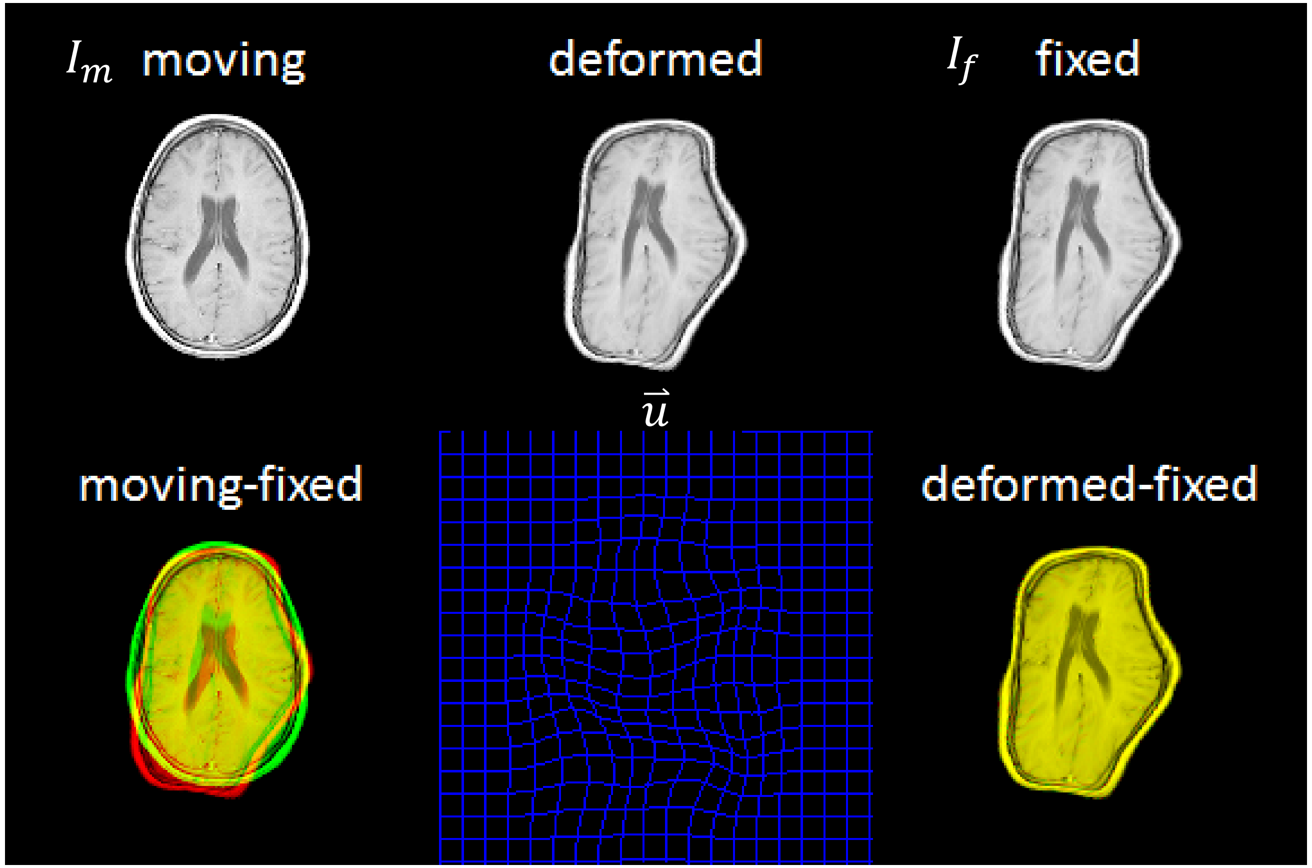
Thirion, 1995

Displacement Field Determination: Optical Flow Equation

Assumptions:

1. Small displacement
2. Intensity of moving image is constant with time

Fixed image(f): deformed image
Moving image(m): undeformed image



Thirion, 1995
Simoncelli *et al.* , 1991

1. Optical flow equation:

$$\vec{\boldsymbol{u}} \cdot \nabla I_f(x,y) = I_m(x,y) - I_f(x,y)$$

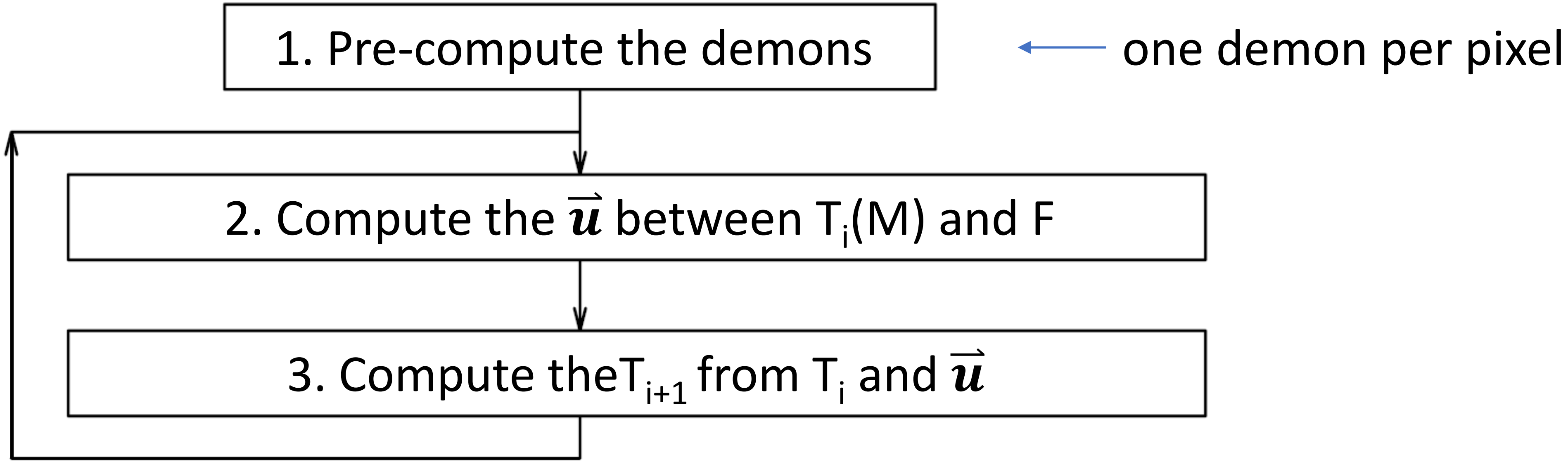
2. Modified displacement field equation:

$$\vec{\boldsymbol{u}} = \frac{[I_m(x,y) - I_f(x,y)]\nabla I_f(x,y)}{\nabla I_f(x,y)^2 + [I_m(x,y) - I_f(x,y)]^2}$$

Zhu et al, 2020

Image Matching as an Iterative Process

Iterative Algorithm:



Final transform T to map moving image M space towards fixed image space F (i.e. **T(M)**→**F**)

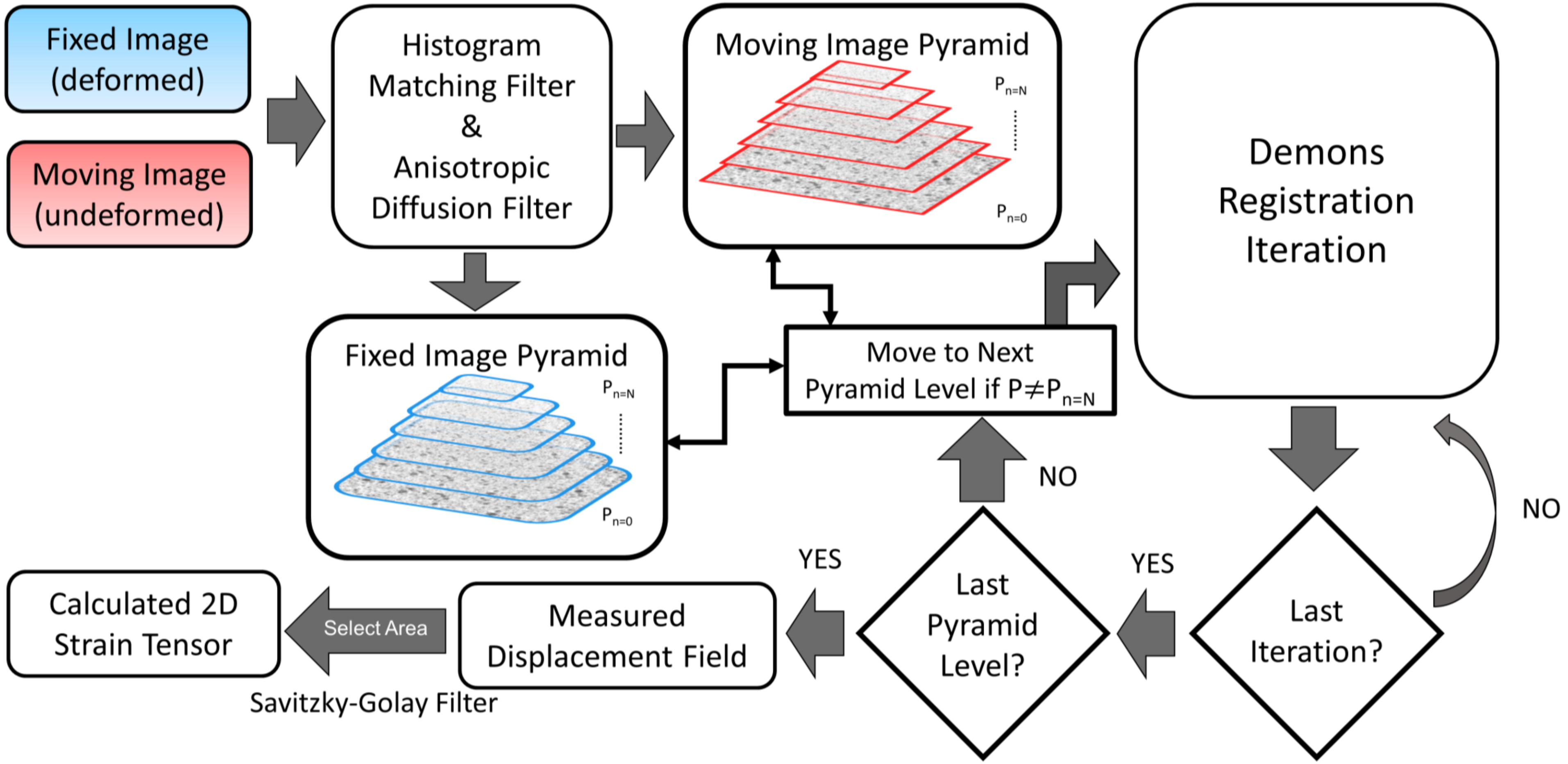
$$T_i(M) = T_{i-1}(M) + \vec{\boldsymbol{u}}_i(M)$$

Thirion, 1995

What about large deformation?

Multiresolution Demons Registration

Down-sample the image -> deformation information from a larger field of view!



Kostelec et al, 1998
Zhu et al, 2020

Computation of Deformation Gradient Tensor

Displacement Gradient Terms:

$$\frac{\partial u_x}{\partial X}(i,j) = \frac{1}{2}[u_x(i+1,j) - u_x(i-1,j)]$$

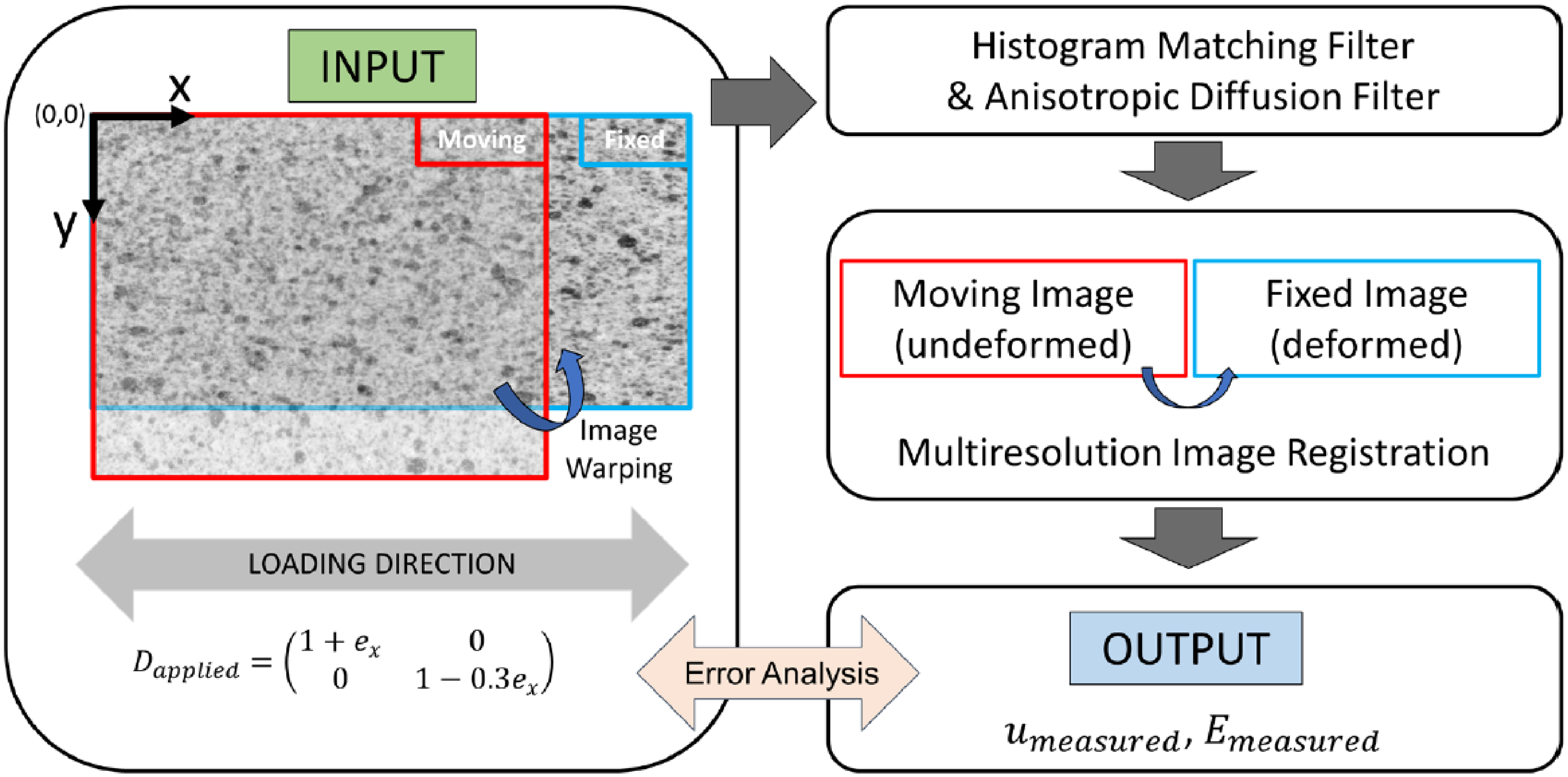
2D-Deformation Gradient Tensor:

$$F = \begin{pmatrix} \frac{\partial x}{\partial X} & \frac{\partial x}{\partial Y} \\ \frac{\partial y}{\partial X} & \frac{\partial y}{\partial Y} \end{pmatrix} = \begin{pmatrix} \frac{\partial (X+u_x)}{\partial X} & \frac{\partial (X+u_x)}{\partial Y} \\ \frac{\partial (Y+u_y)}{\partial X} & \frac{\partial (Y+u_y)}{\partial Y} \end{pmatrix} = \begin{pmatrix} 1+\frac{\partial u_x}{\partial X} & \frac{\partial u_x}{\partial Y} \\ \frac{\partial u_y}{\partial X} & 1+\frac{\partial u_y}{\partial Y} \end{pmatrix}$$

Green-Lagrange Strain Tensor:

$$E = \frac{1}{2}(F^T \cdot F - I) = \begin{pmatrix} E_{xx} & E_{xy} \\ E_{yx} & E_{yy} \end{pmatrix}$$

Validation Experiment : Computationally Deformed Images

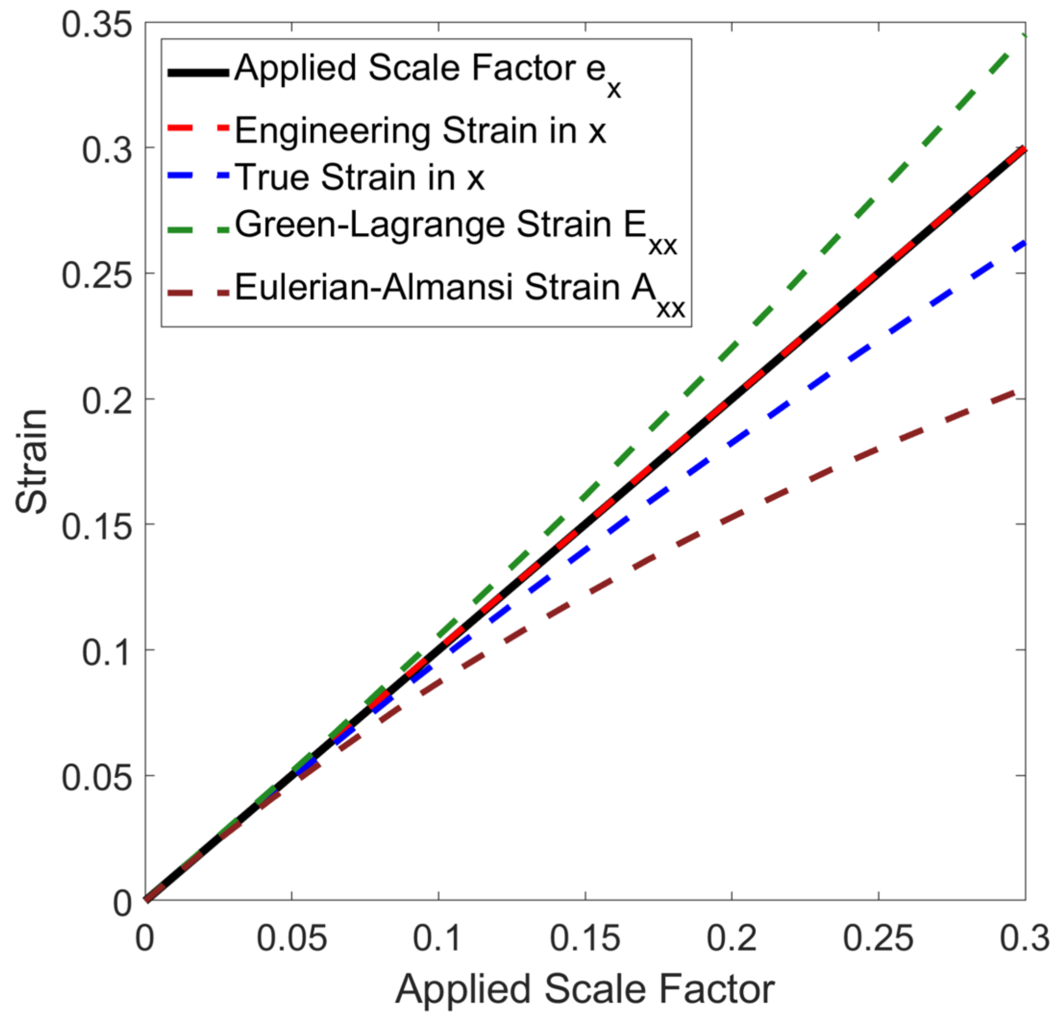


Applying an in-plane elastic stretch

Zhu et al, 2020

Image Warping via Inverse Mapping

Applied Scale Factor vs Resultant Strains



Define the geometric transformation:

$$D = \begin{pmatrix} 1 + e_x & 0 \\ 0 & 1 - 0.3e_x \end{pmatrix}$$

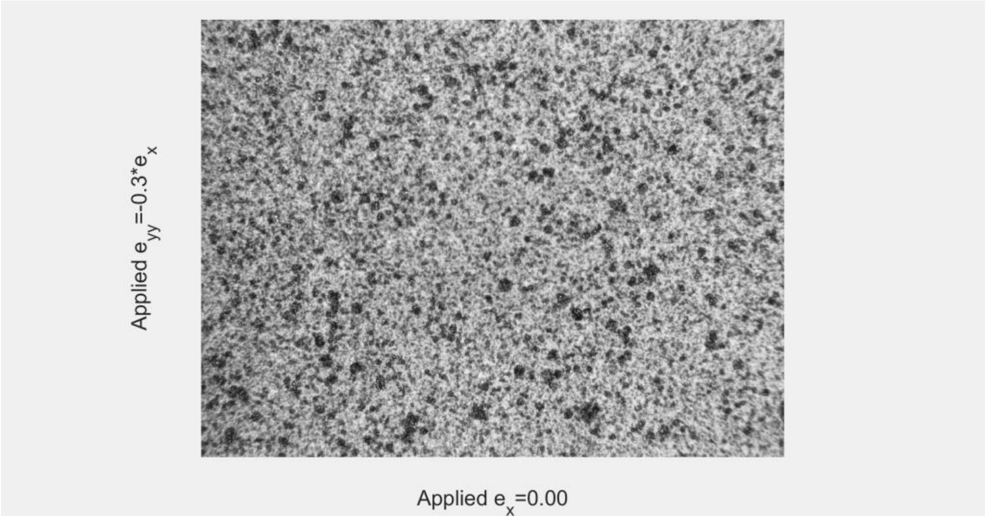
Image warping with inverse mapping:

$$X = D^{-1}x$$

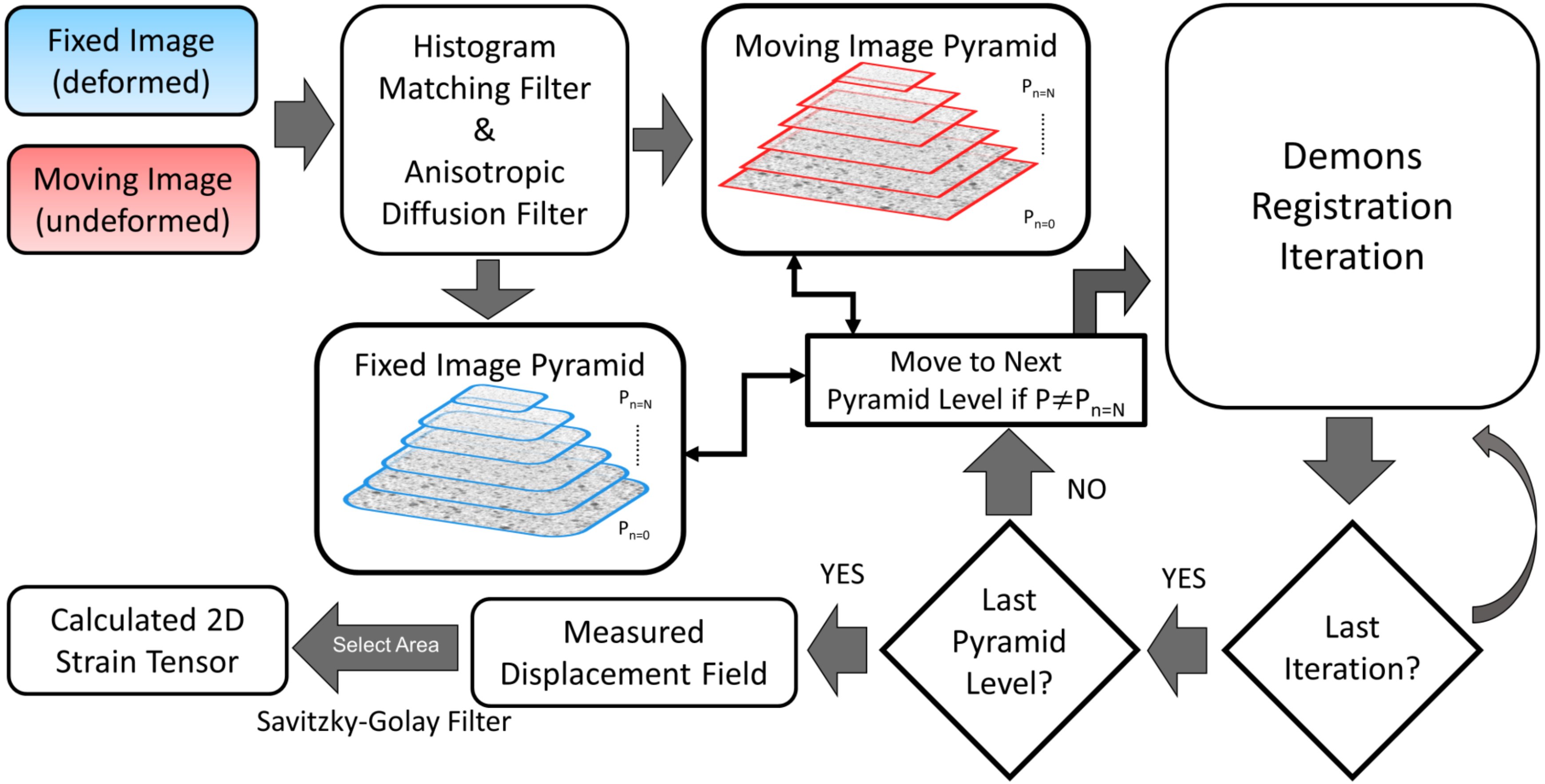
X: undeformed coordinates (floats)
x: deformed coordinates (integers)

Resampling:

Linear/nearest/**cubic** interpolation



Parametric Study



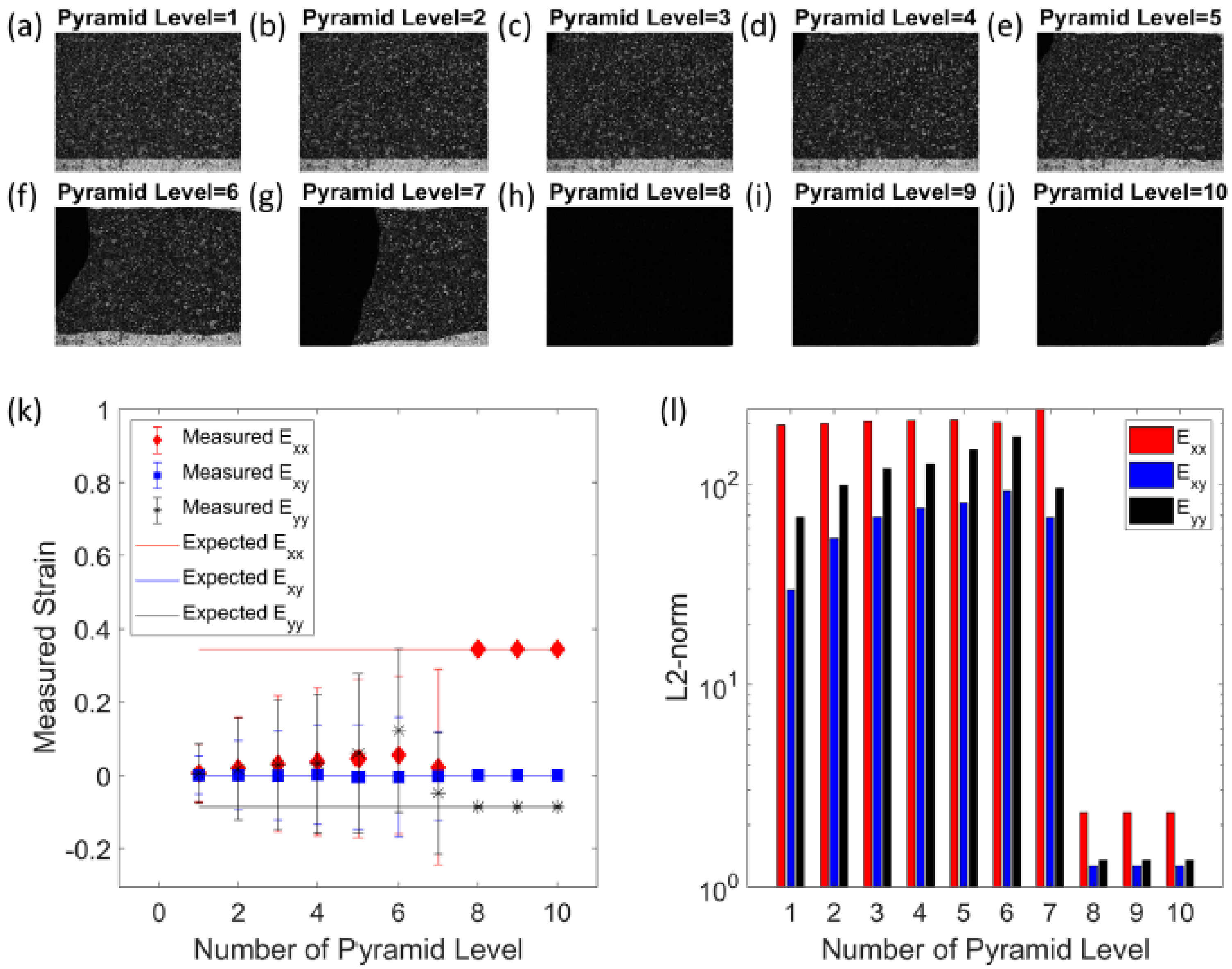
Number of pyramid levels

Number of registration iterations

SG-filter size

Apply a maximum e_x=0.3

Effect of Pyramid Level on Registration Accuracy



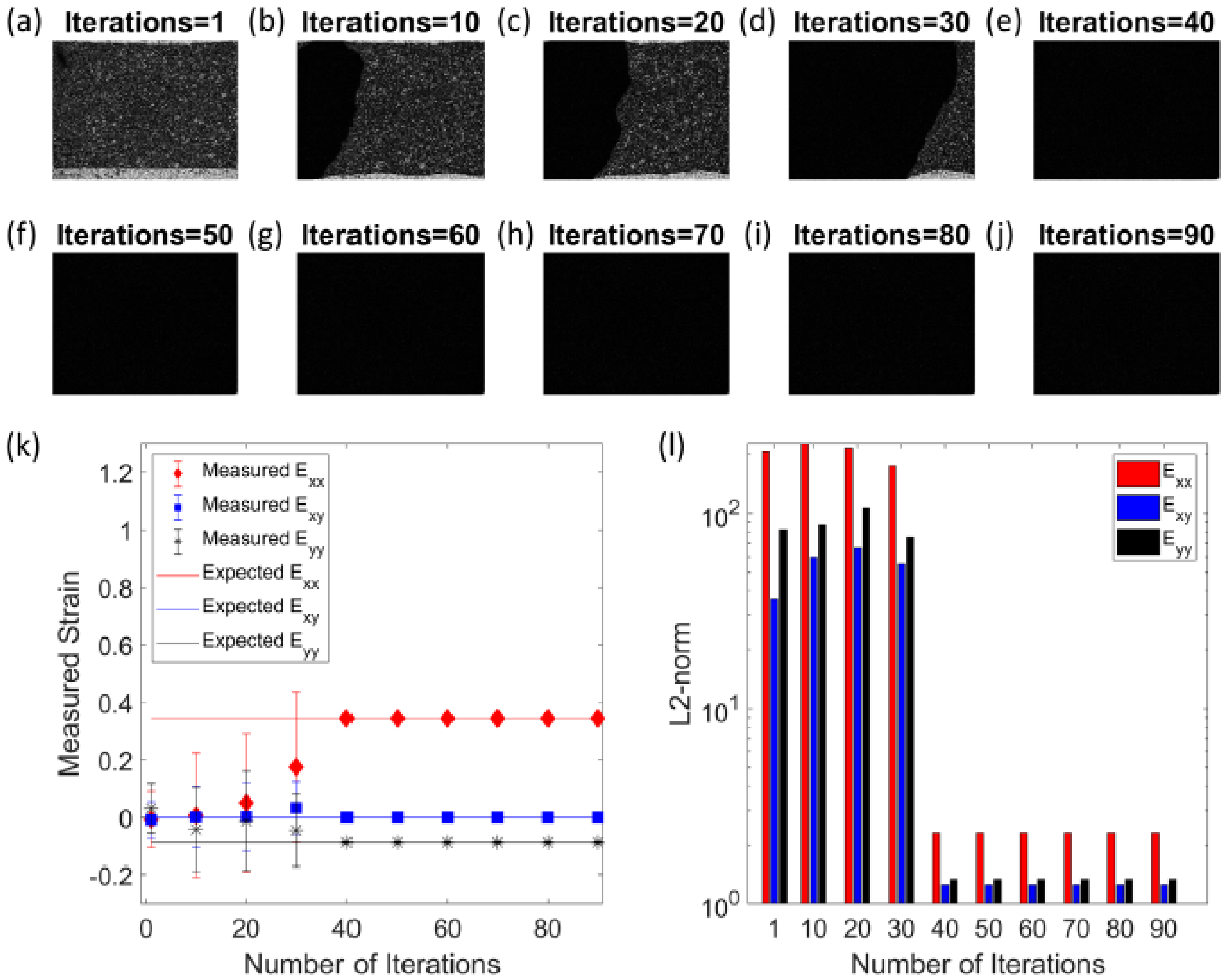
100 iterations at each pyramid level

SG-filter size: 21 by 21

L2-norm: image similarity metric

Number of Pyramid Level>8

Effect of Number of Iterations on Registration Accuracy



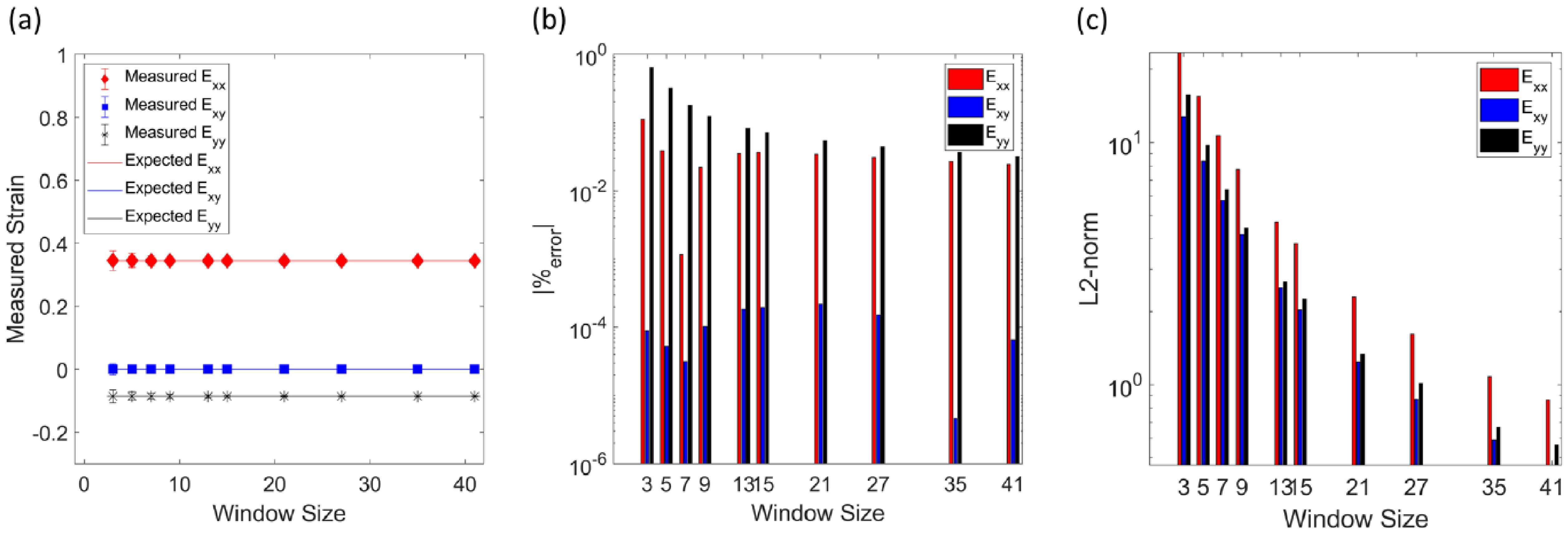
Number of pyramid level=8
SG-filter size: 21 by 21

Number of Iterations>=40

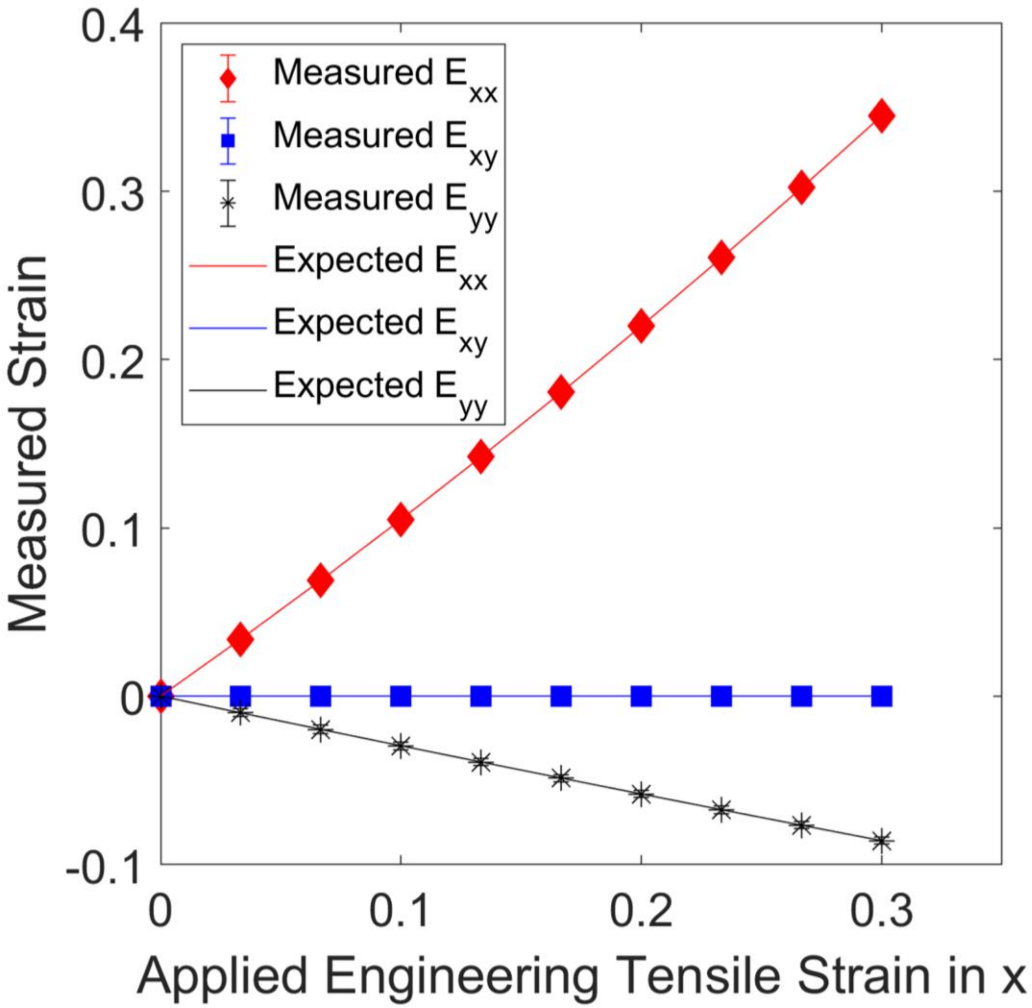
Effect of SG-filter size on Registration Accuracy

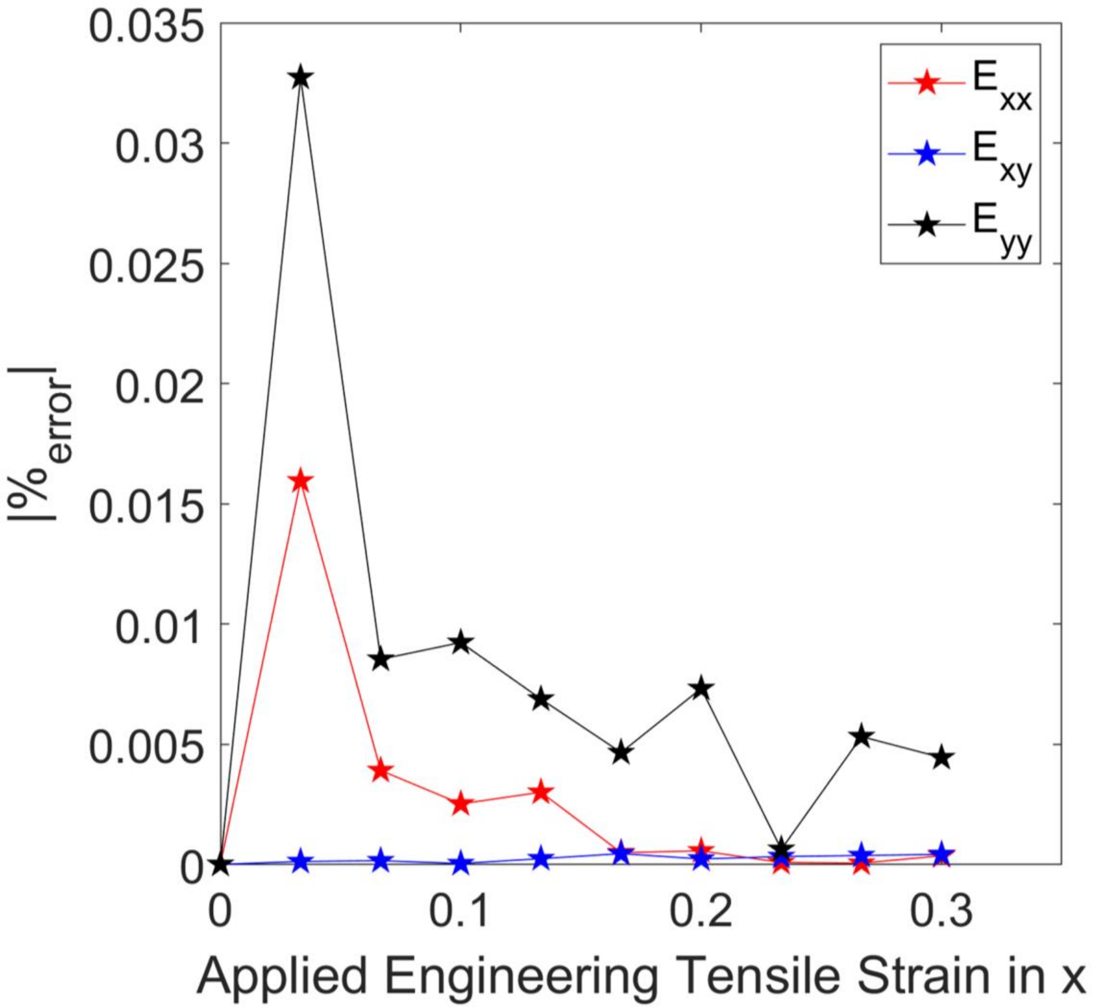
Number of pyramid level=8
Number of Iterations=40

- Size of SG Filter~ 21 by 21
- SG filter affects the precision



Strain Error Analysis (Computationally Deformed Images)

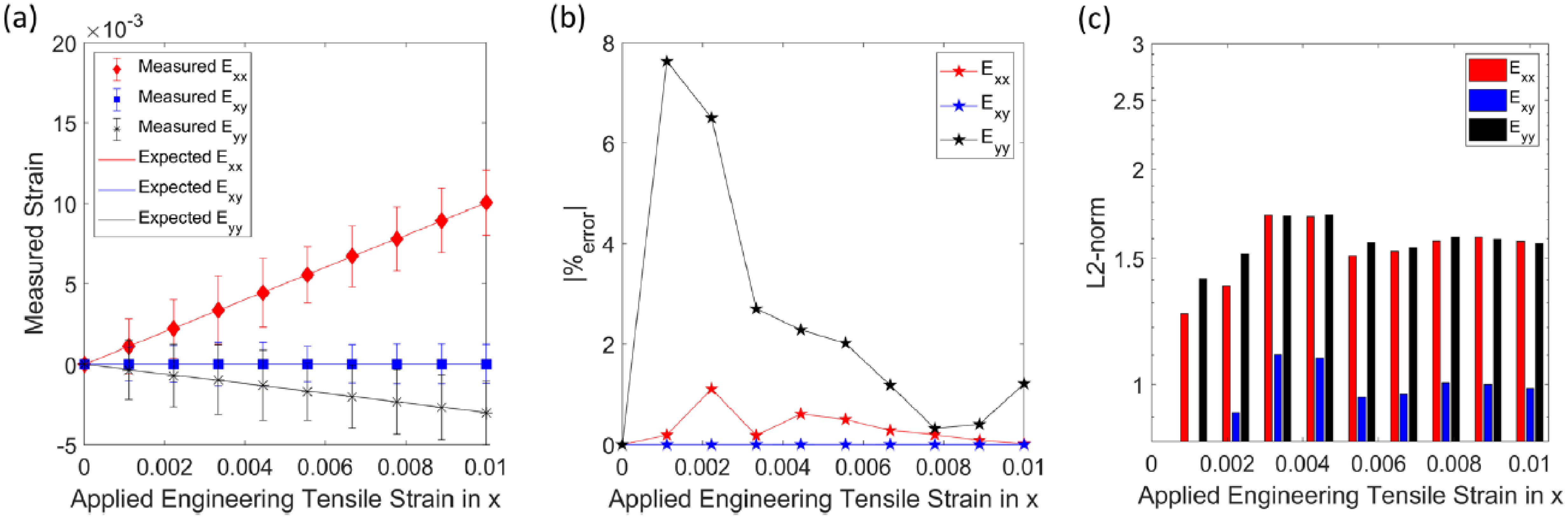




SG=21 *21
Pyramid =8
Iterations =40

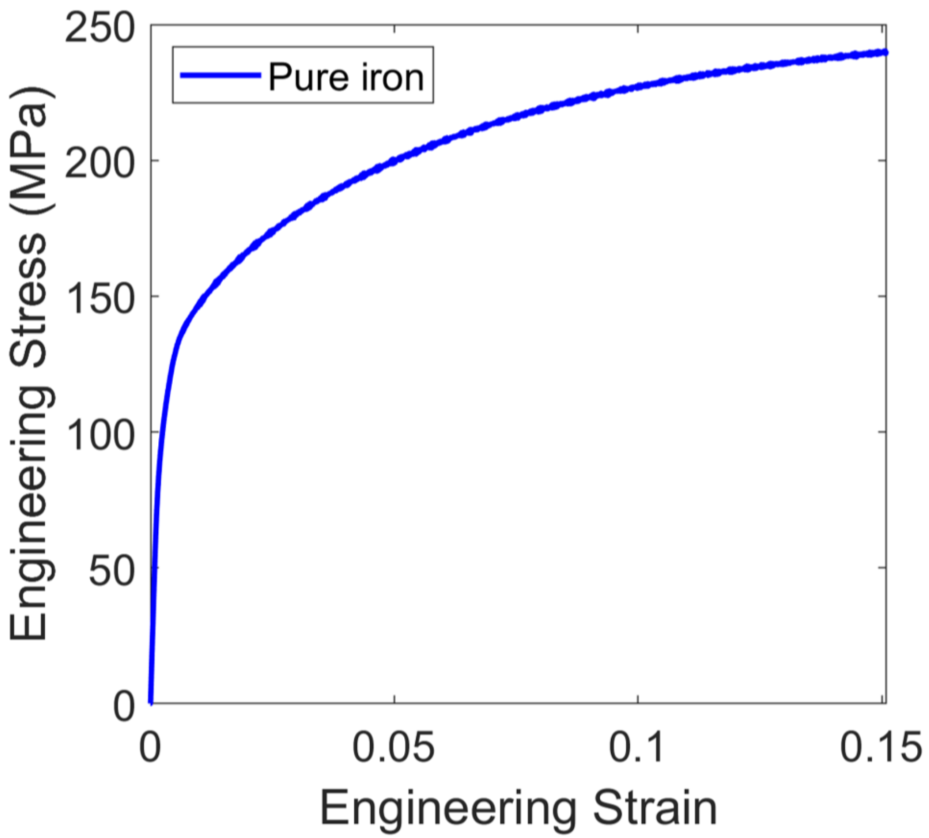
Percentage strain error<0.035% for all components

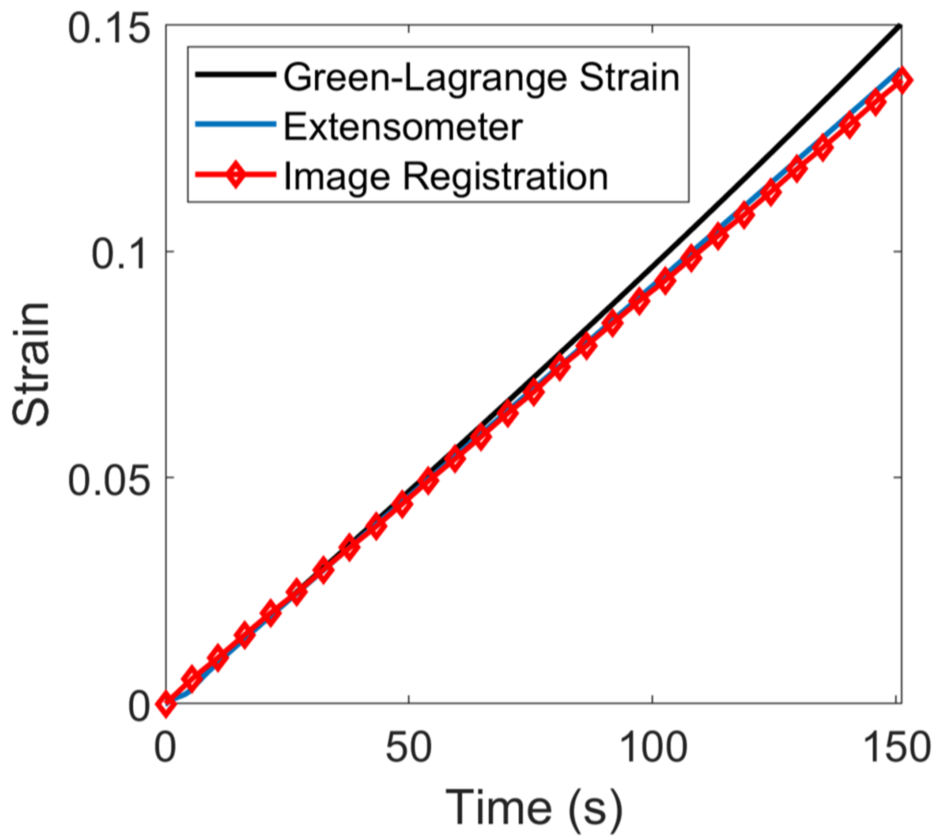
Strain Error Analysis (Computationally Deformed Images)



WARNING: not very sensitive to subpixel level shift information

Experimental Validation: Tensile Test



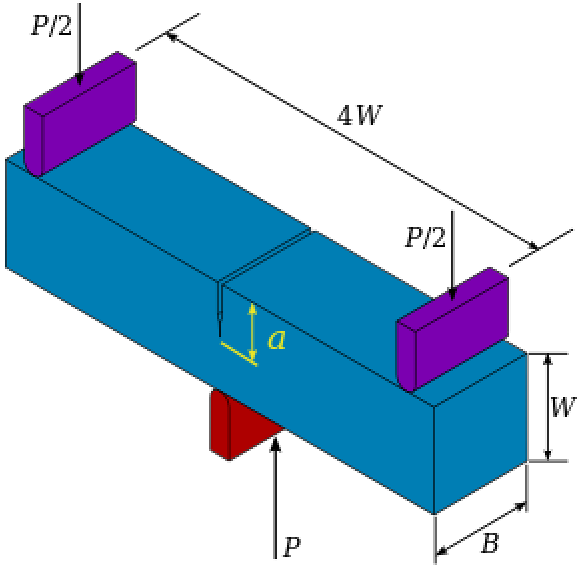


Extensometer

Image registration approach slightly underestimates the expected Green-Lagrange strain probably due to out-of-surface displacement caused by significant rotation of grains.

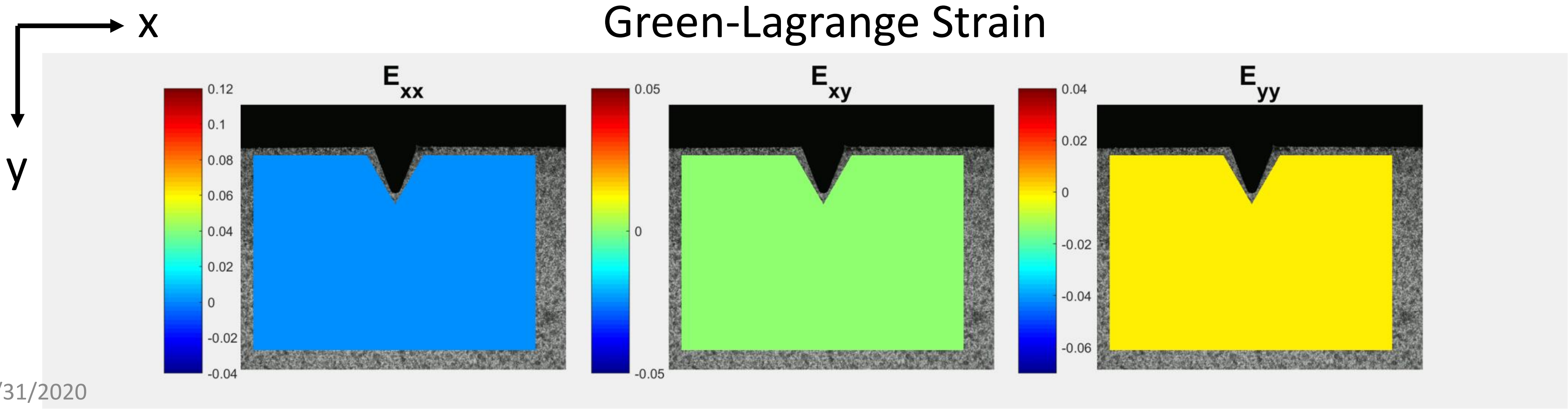
Experimental Validation: Bending Test

Three Point Bending

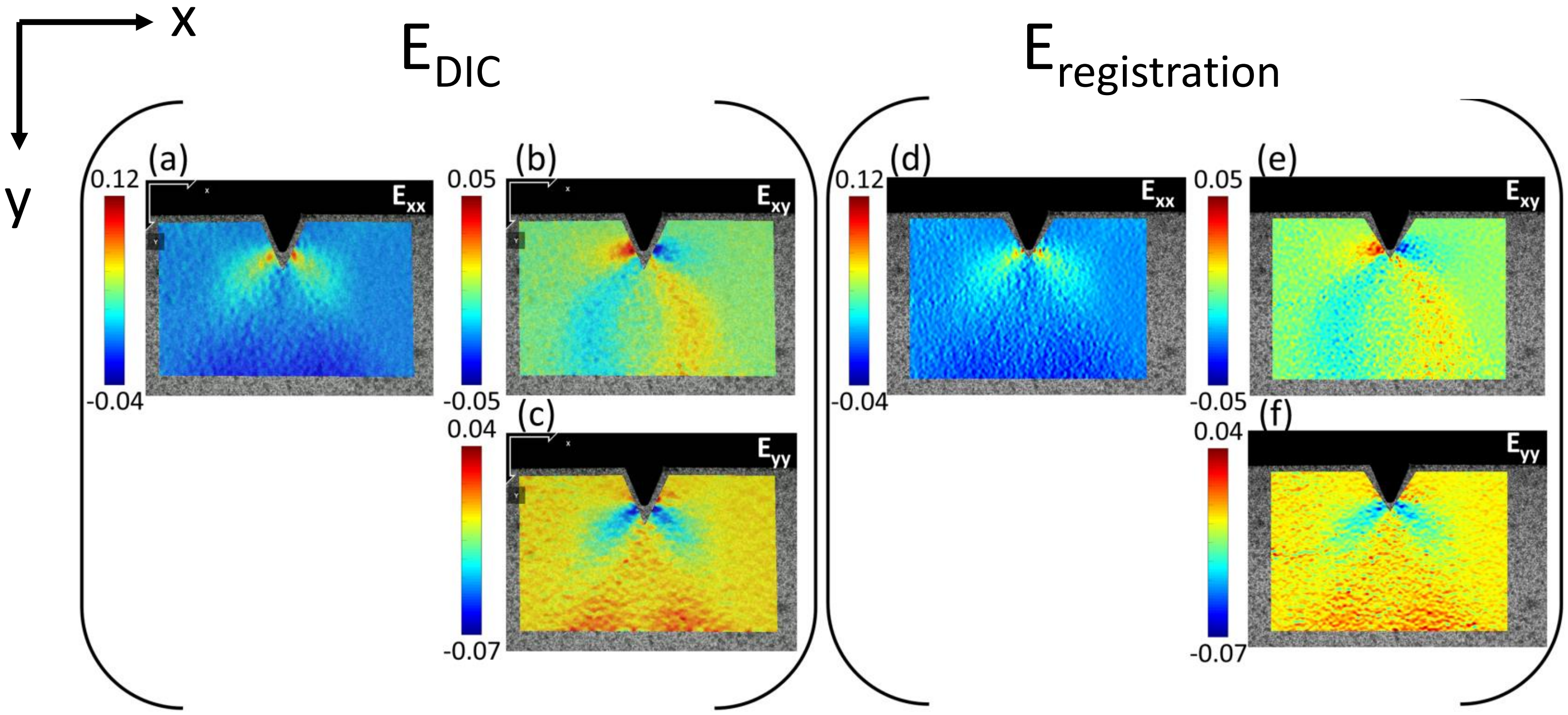


Three Point Bending (Video)

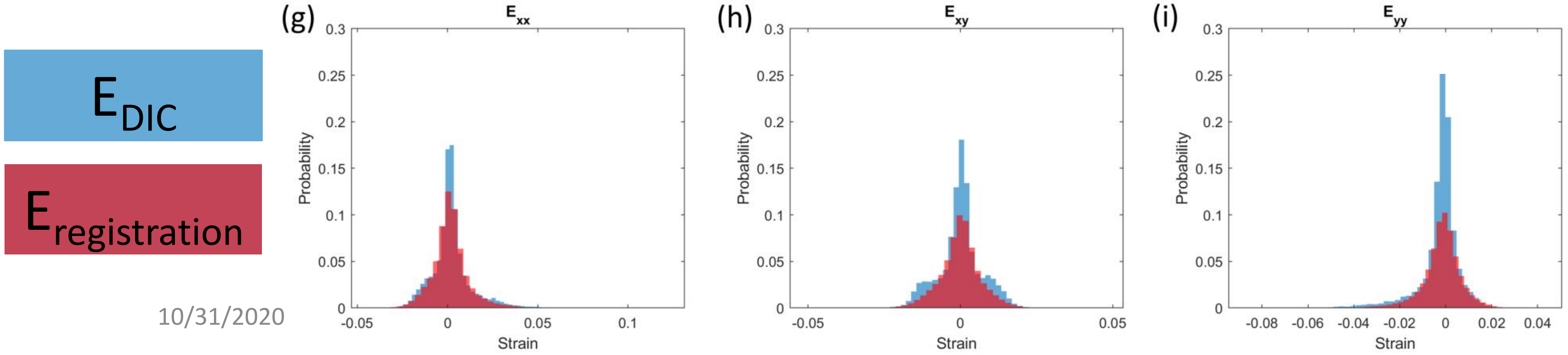
Green-Lagrange Strain



Experimental Validation: Bending Test



- DIC calculated using Ncorr
- Nice agreement between the two methods.
- Small difference on the shoulders of E_{xy} component



Summary

- Multiresolution image registration approach is an effective method to map large surface strain.
- A good starting point for the variables in the registration could be: 8 pyramid level, 40 iterations and SG filter size 21 by 21.
- Percentage error in the measured Green-Lagrange strain tensor components <0.035%.
- Validation with tensile test and bending test showed good agreement with extensometer and DIC calculation respectively.

Zhu, C., Wang, H., Kaufmann, K. and Vecchio, K.S., 2020. A computer vision approach to study surface deformation of materials. *Measurement Science and Technology*, *31*(5), p.055602.

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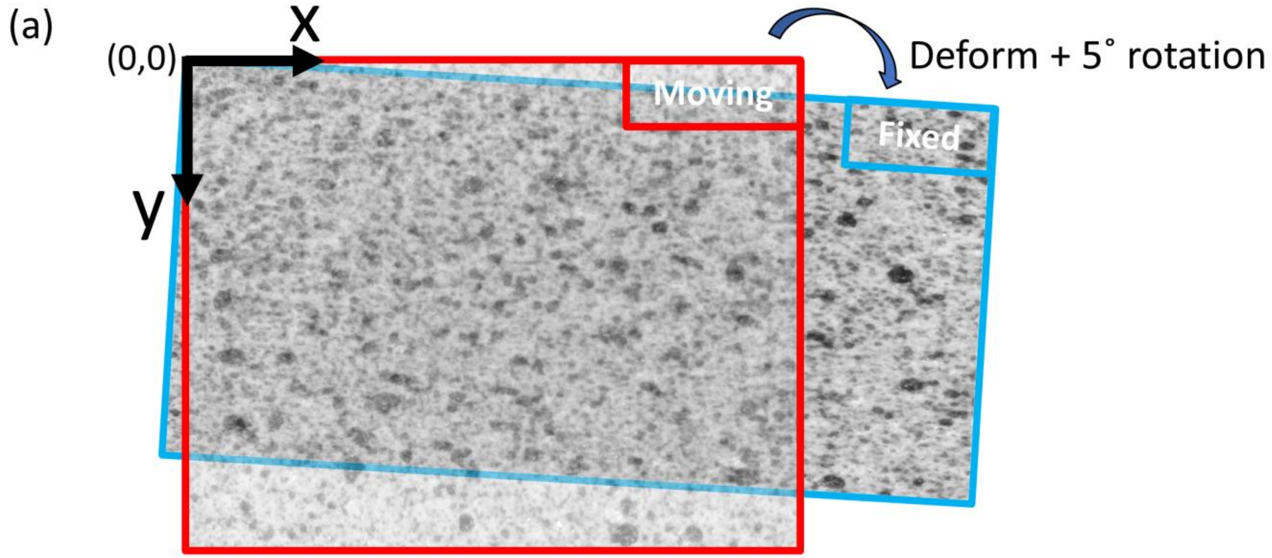
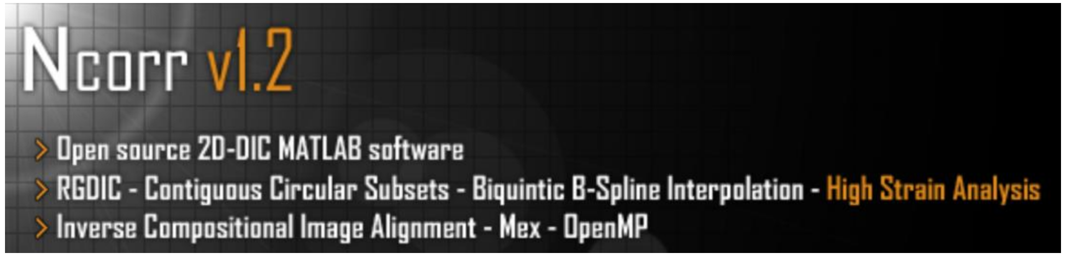
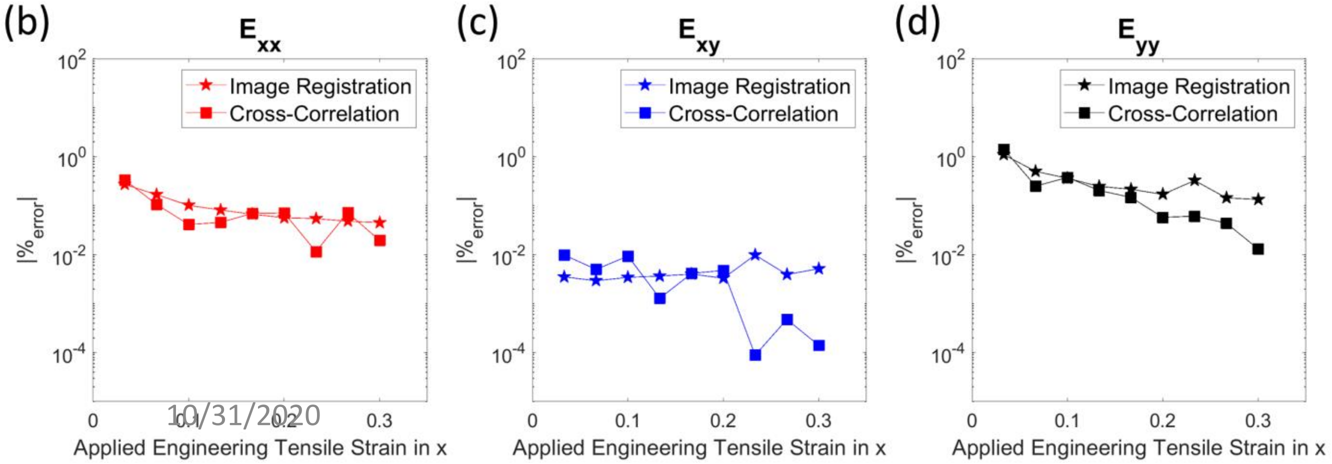
Strain Error Analysis under Rigid Body Rotation (Computationally Deformed Images)



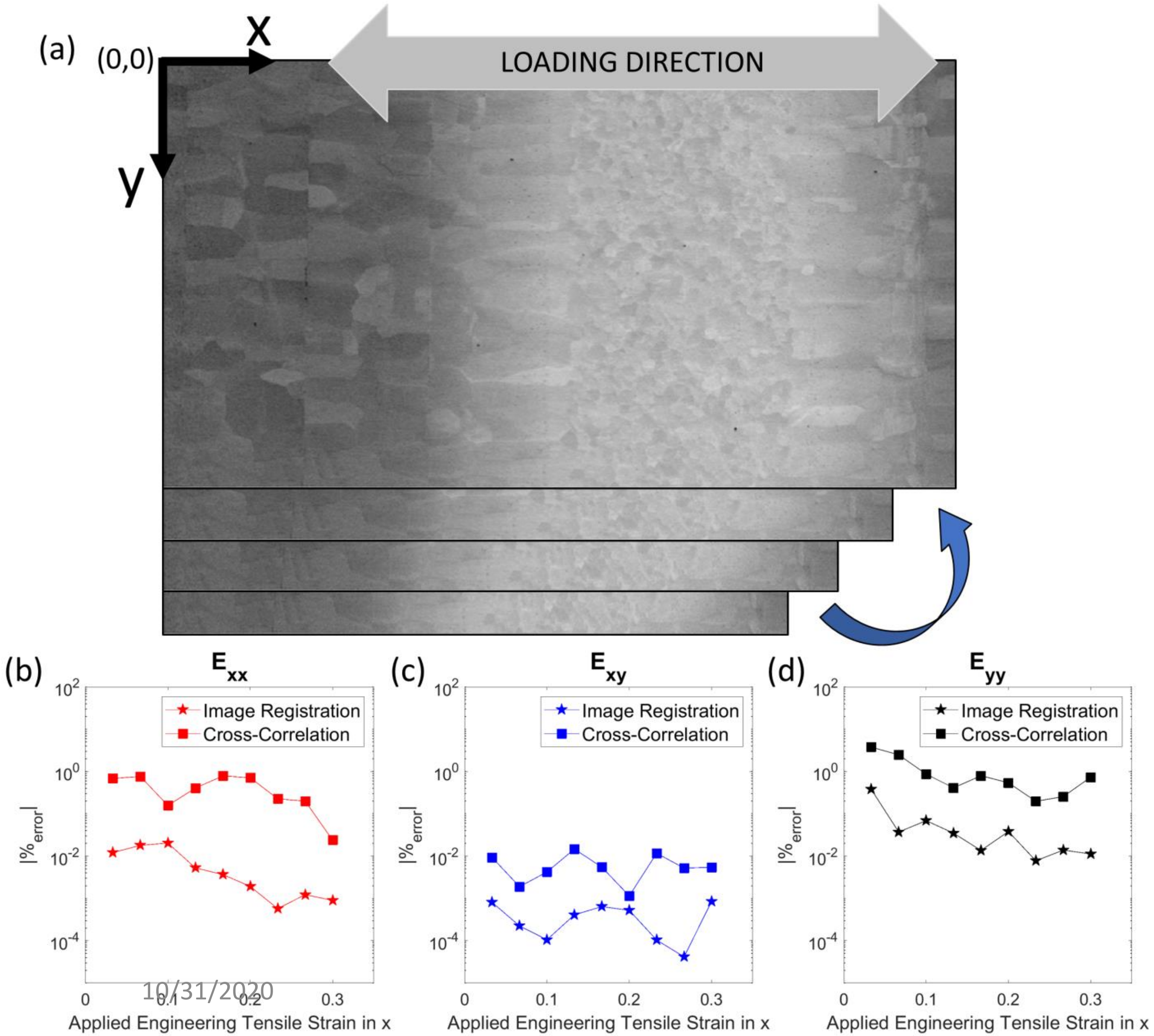


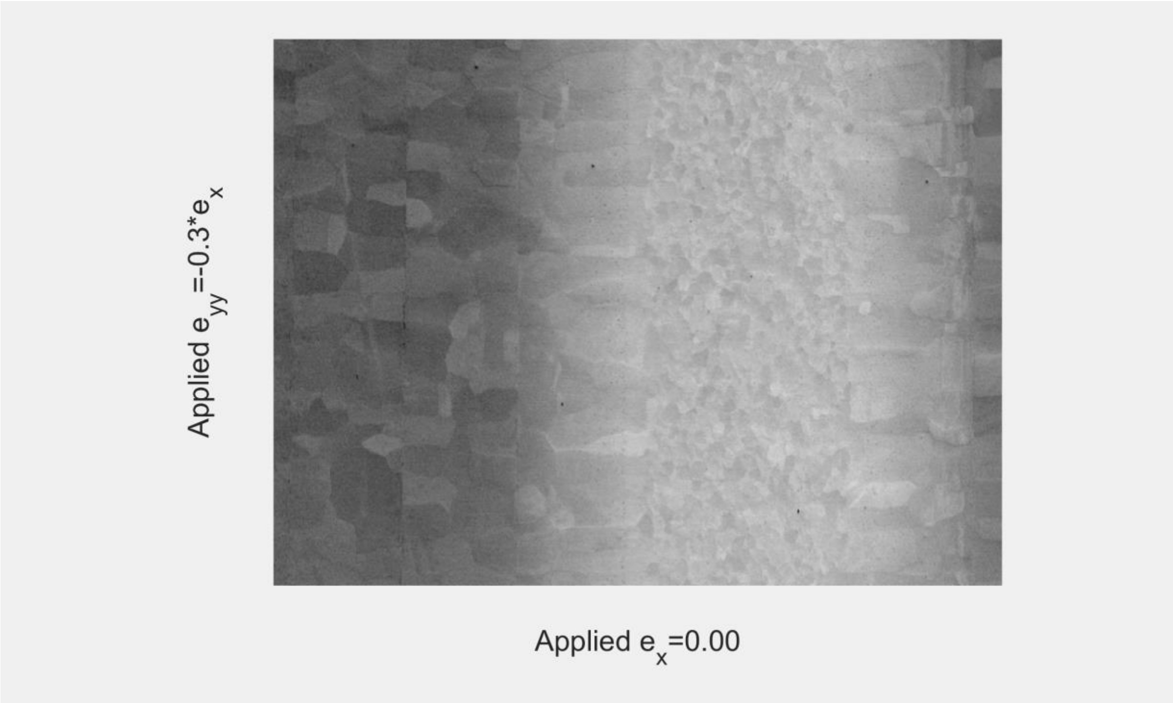
The strain error obtained using image registration is similar to the performance of DIC (Ncorr).

'cross-correlation' represents the traditional DIC performed with Ncorr software.



Strain Error Analysis using Natural Pattern (Computationally Deformed)





The image registration method performs significantly better than the DIC.