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MatchID
Image Correlation & Material Identification

Integration of DIC into VFM: how do measurements contribute to identified material properties?

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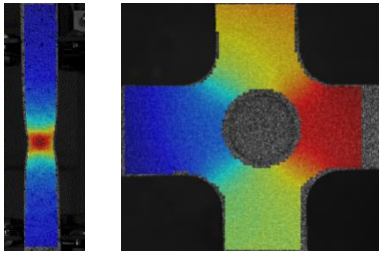
*University of Southampton

Celebrating 50 years of BSSM:
Showcase on leading edge experimental techniques,
4th November 2014 , London UK

Motivation

Full-Field measurements



- Grid
- Photoelasticity
- Interferometry
- Digital Image Correlation
- …

Measurement errors

Mechanical properties of materials

- Finite element updating
- Constitutive equation gap
- Equilibrium gap
- Reciprocrity gap
- Virtual Fields Method
- …

Identification errors

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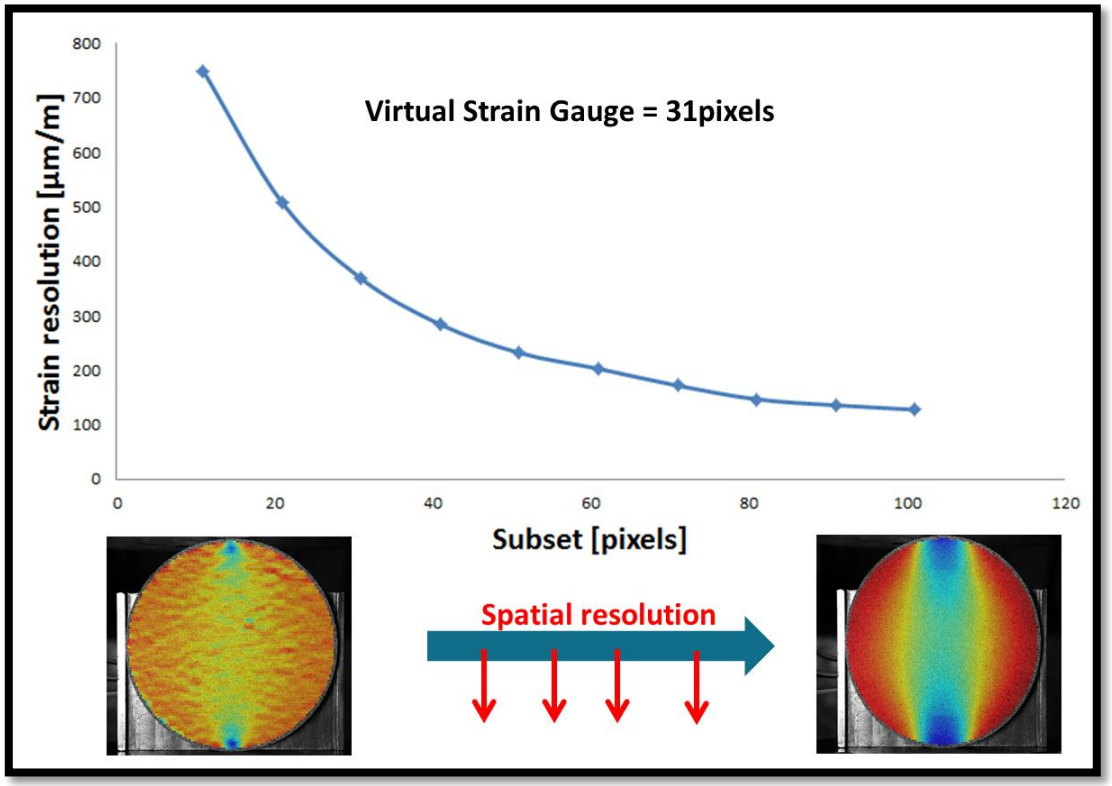
DIC is a complex and non-linear process

… results depend on many parameters:

- Correlation criterion
- Interpolation routines
- Shape functions
- Regularization parameters:
  - Subset
  - Virtual strain gauge size
- Speckle pattern
- …



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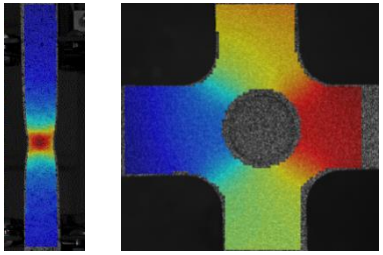
Motivation

Full-Field measurements



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Measurement errors

Mechanical properties of materials

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Identification errors

Any realistic UQ on the mechanical parameters requires to take into account the measurement process

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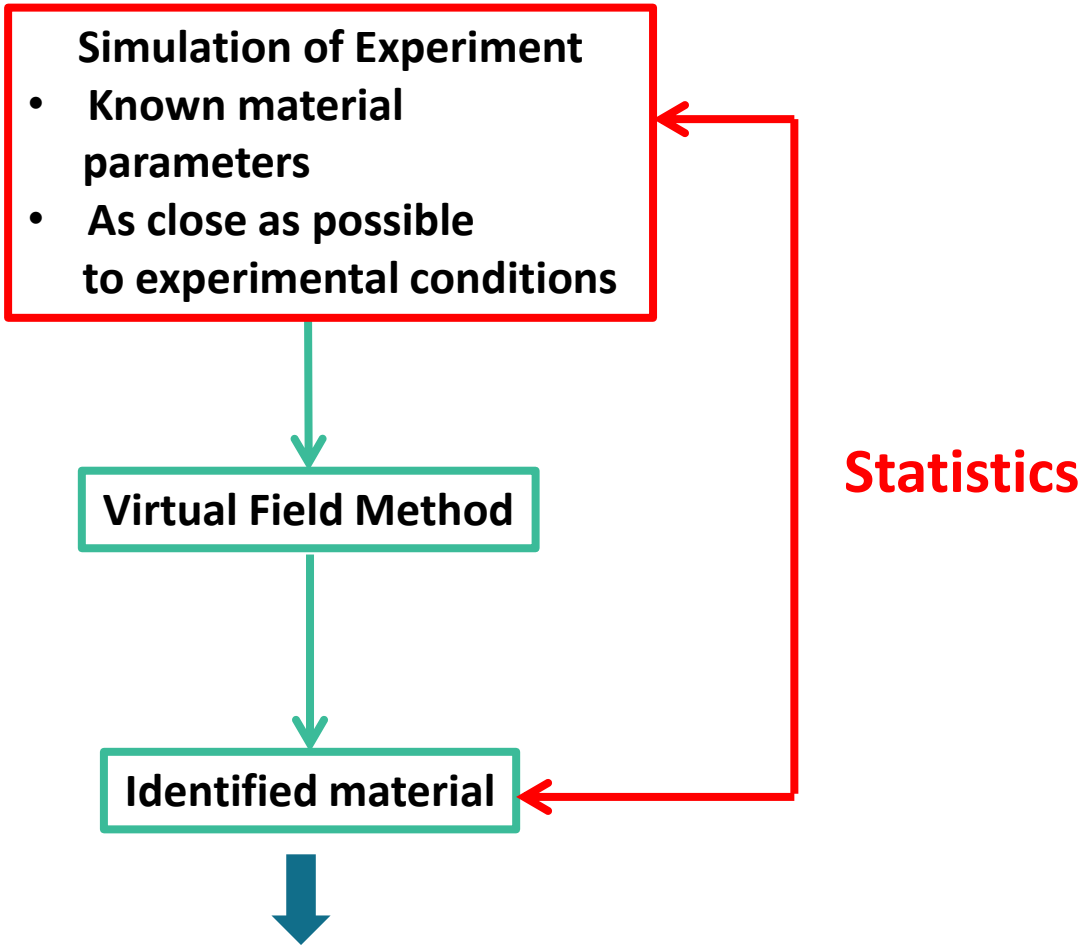
How?



- **Confidence margins for** the determined material parameters
- **Optimization** of test design (geometry of specimen, smoothing , …)

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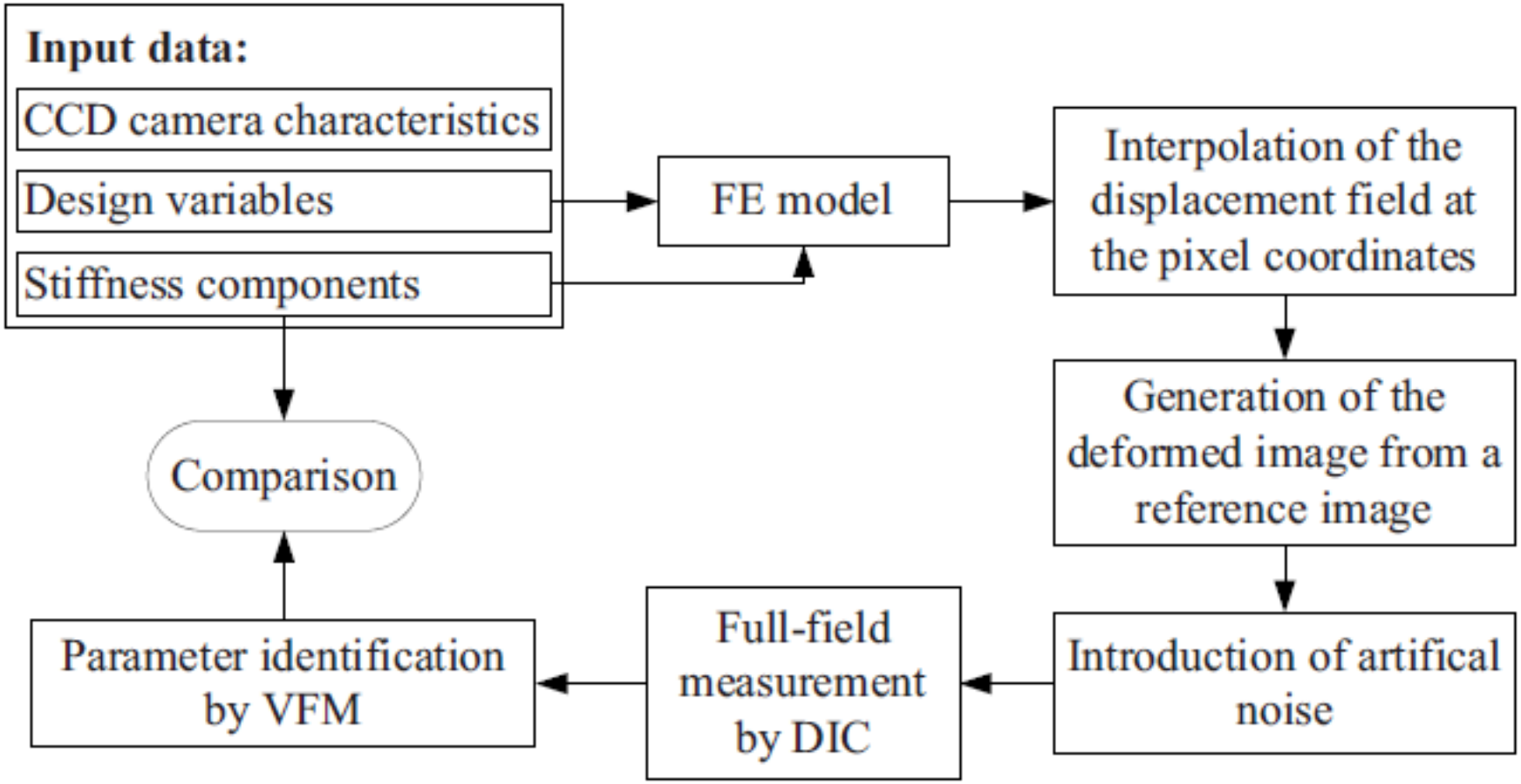
Simulate the whole identification chain



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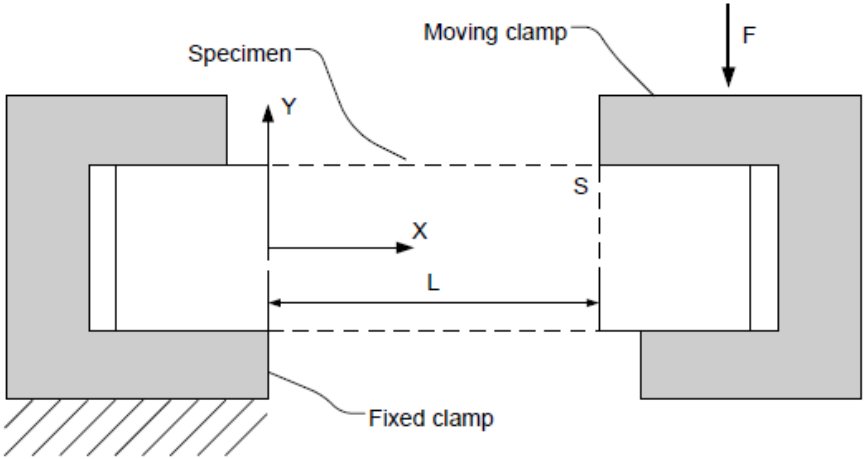
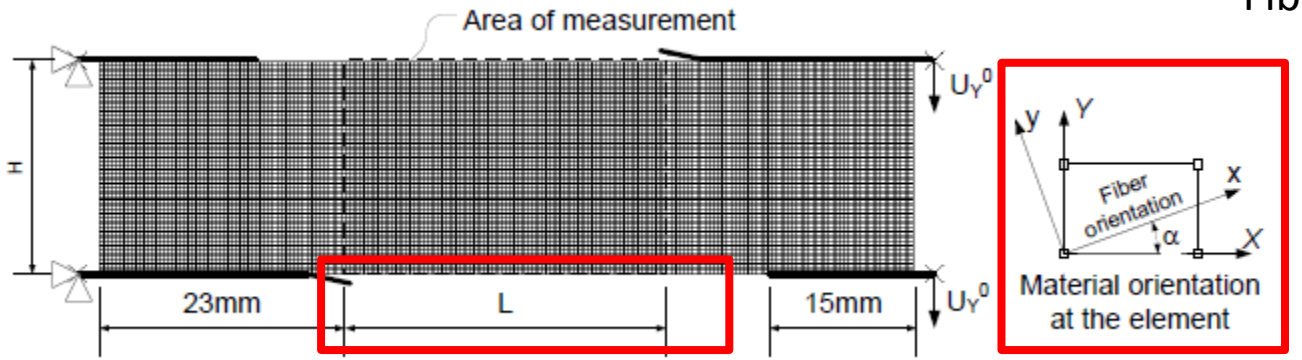
Case study : unnotched Iosipescu test



- Glass/epoxy unidirectional composite
- Linear elastic orthotropic

Stress state is composition of compression, bending and shear

- **Design variables**:
  - Free length L
  - Fibre orientation α



Rossi M., Pierron F., International Journal of Solids and Structures, 2012.

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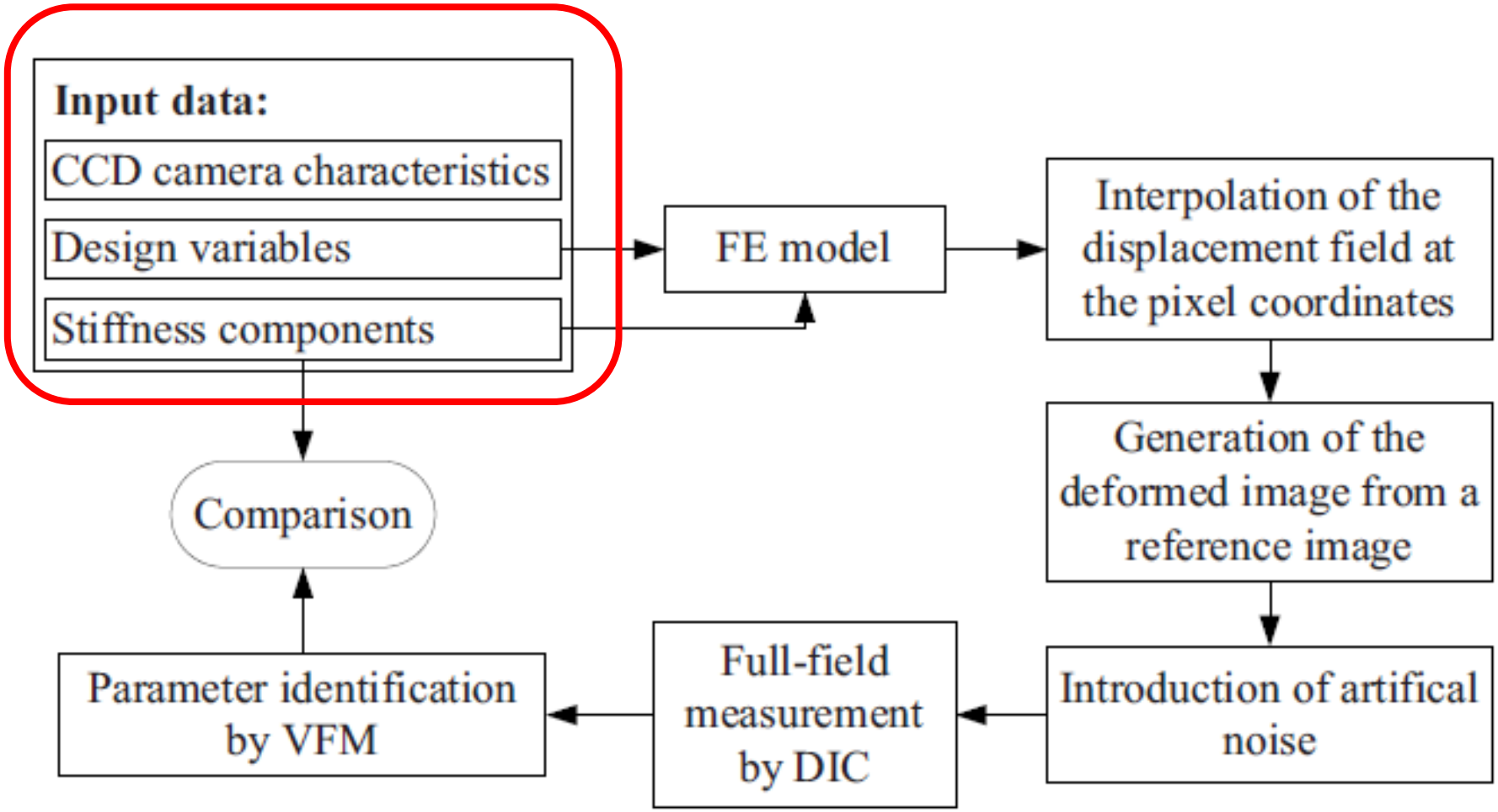
Simulate the whole identification chain



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Input data

Design Variables

- Free Length L:
  10 -> 60 mm ; L =2mm
- Fibre orientation α:
  0^o -> 90^o ; α += 10^o

Camera characteristics

- spatial resolution: 1320 x 1024
- Dynamic range: 8-bit

Stiffness components

Stiffness		Maximum stress	
Q_{xx} (MPa)	40920	S_{+x} (MPa)	1000
Q_{yy} (MPa)	10230	S_{-x} (MPa)	-600
Q_{xy} (MPa)	3069	S_{+y} (MPa)	40
Q_{ss} (MPa)	4000	S_{-y} (MPa)	-100
		S_s (MPa)	40

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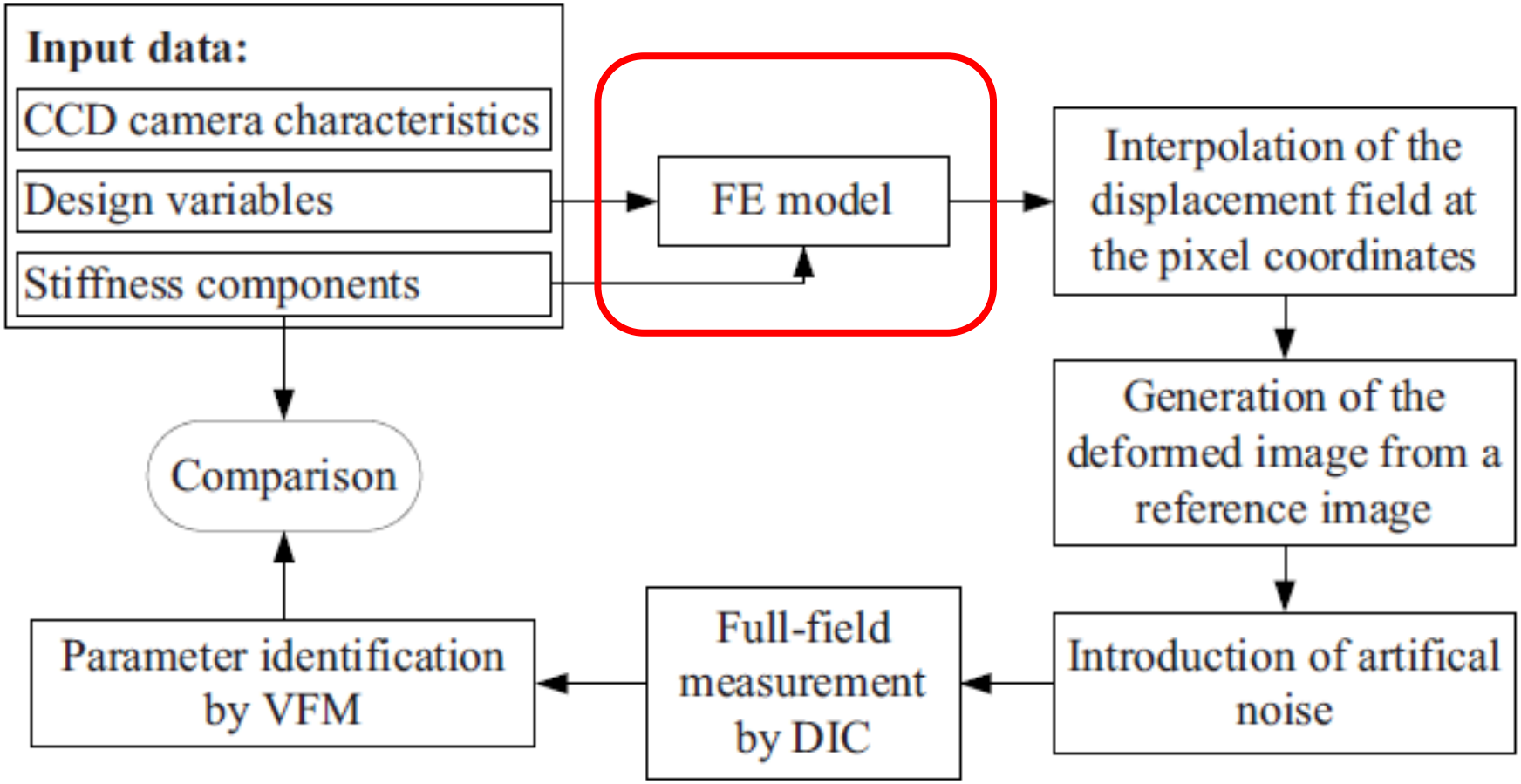
Simulate the whole identification chain



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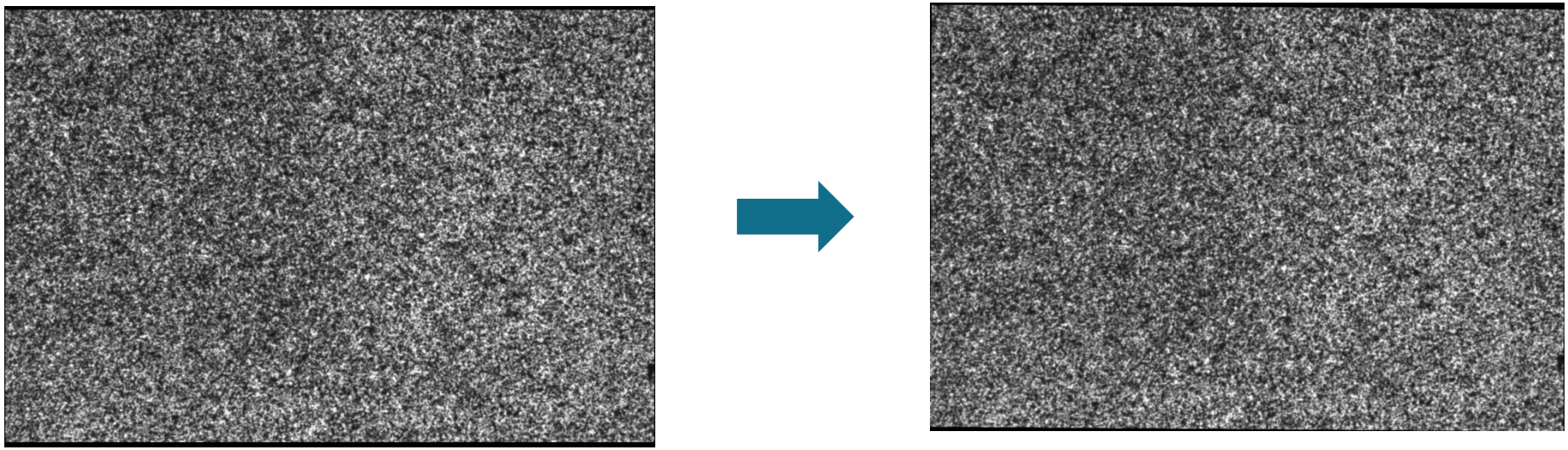
FE generated displacement map + image of real speckle pattern



SPECKLE DEFORMATION

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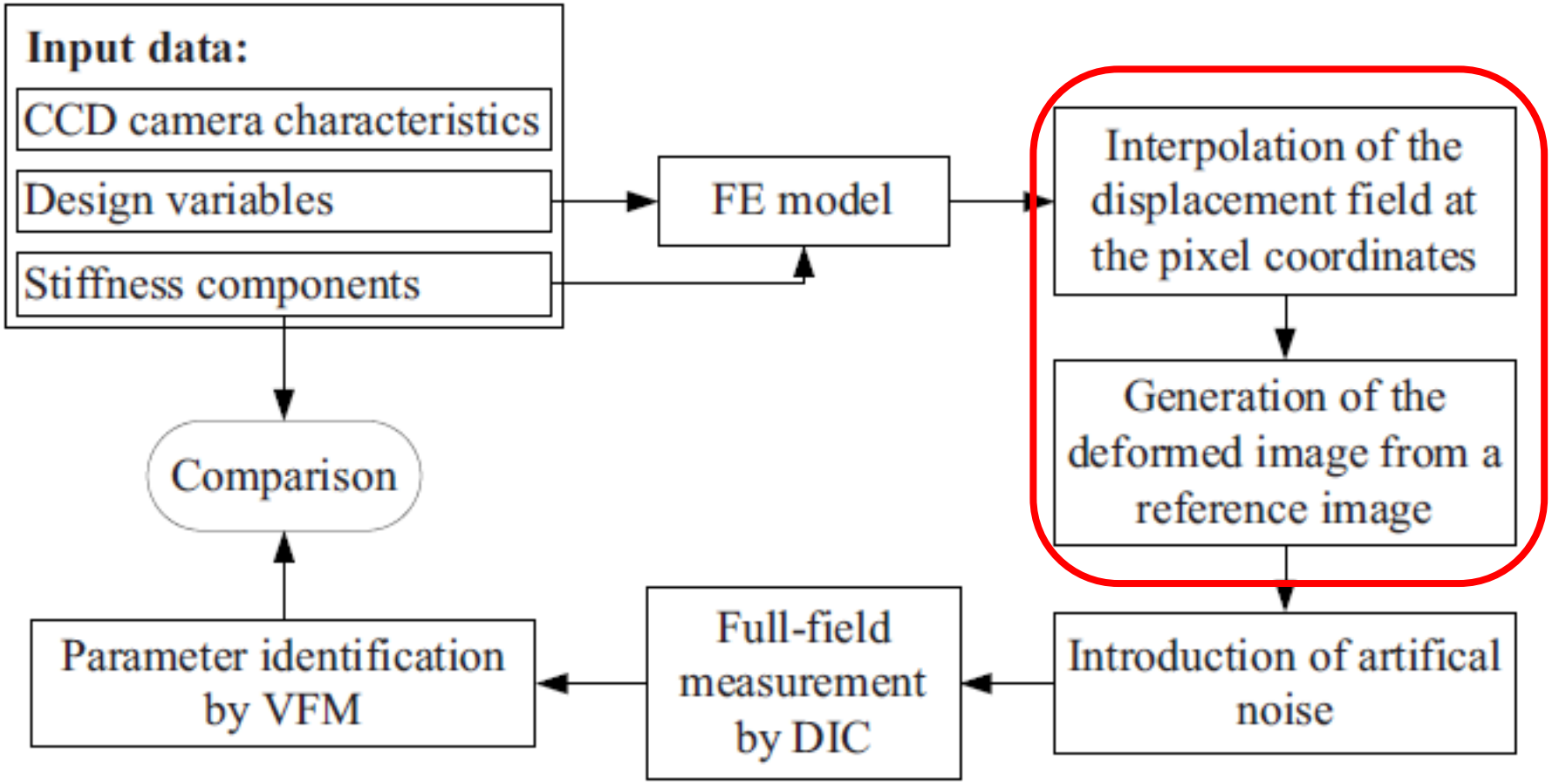
Simulate the whole identification chain



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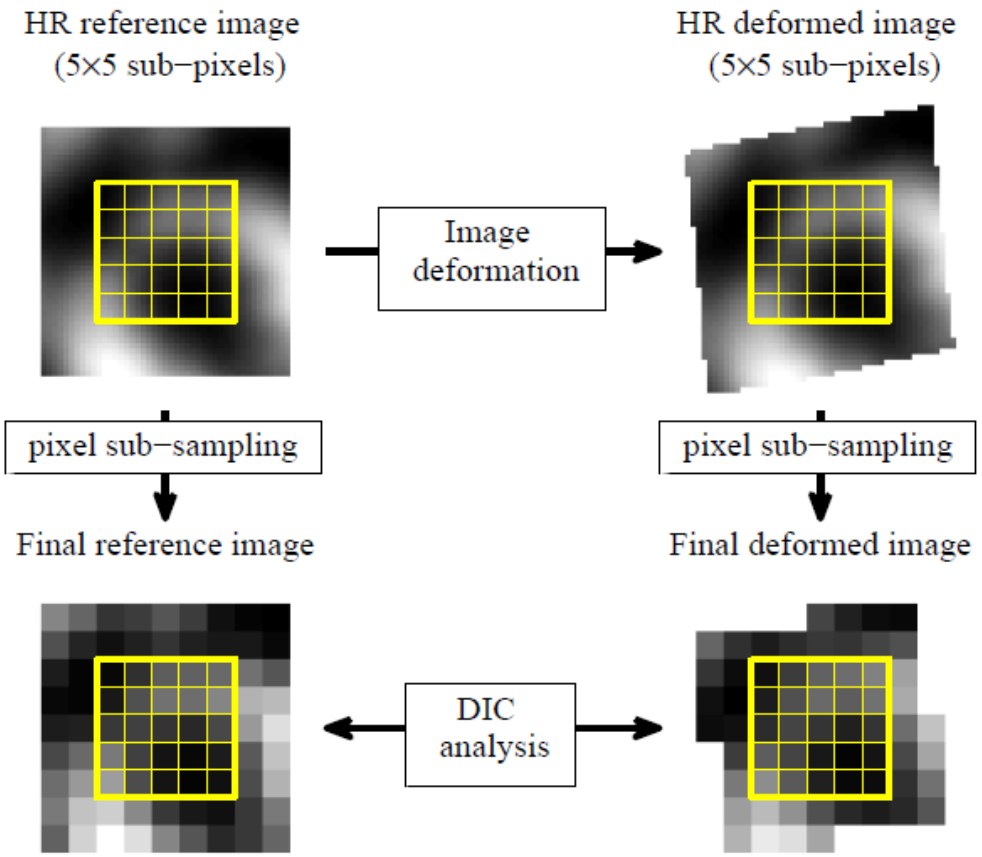
Synthetic image generation

Numerical deformation errors should be as low as possible: SUB-SAMPLING



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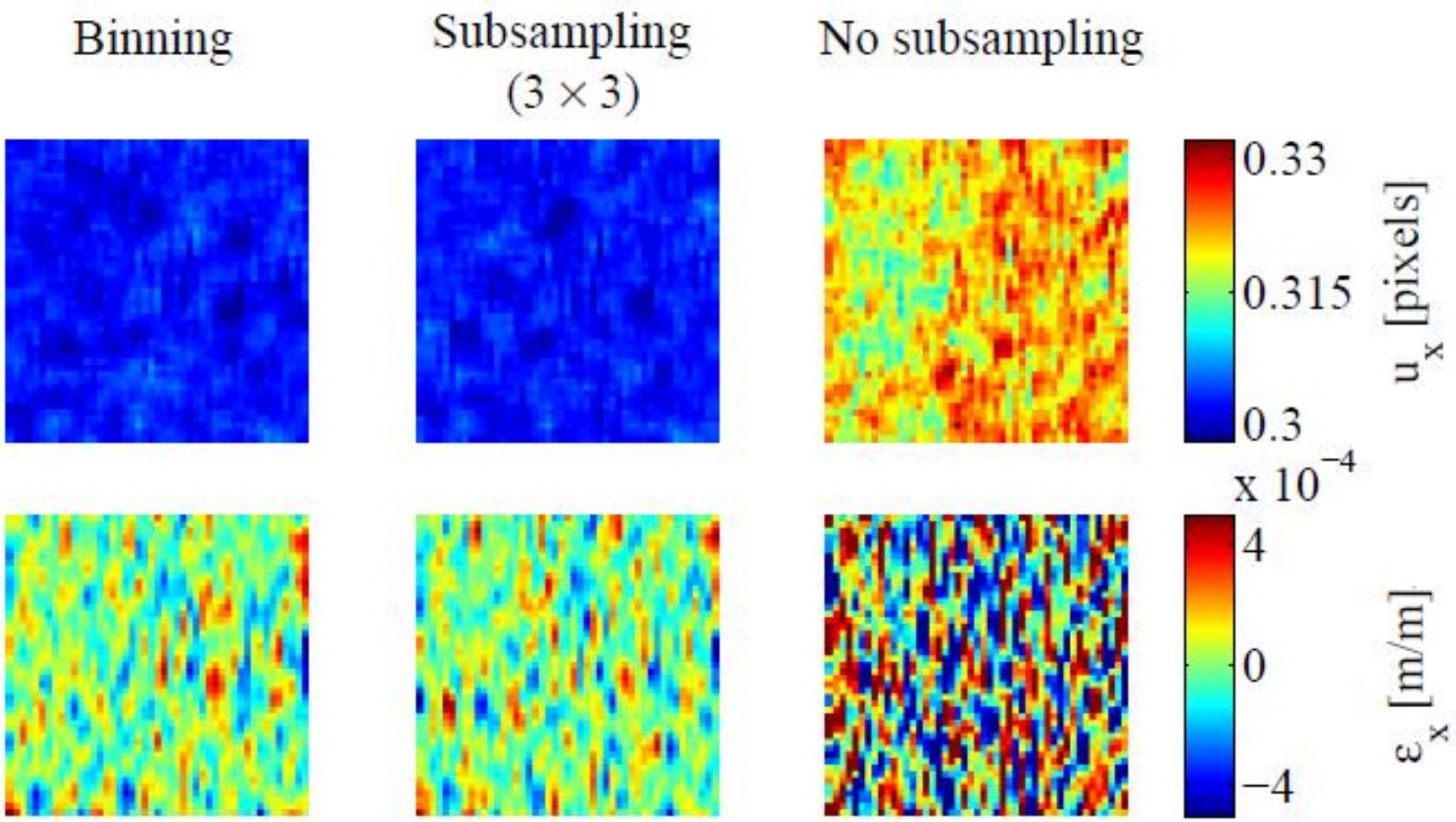
Synthetic image generation: validation



P. Reu, *Experimental and numerical methods for exact subpixel shifting*, Experimental Mechanics 51 (2011) 443-452

Rossi M., Lava P., Pierron F., Debruyne D. and Sasso M. *Effect of DIC spatial resolution, noise and interpolation error on identification results with the VFM*, submitted to Strain (2014)

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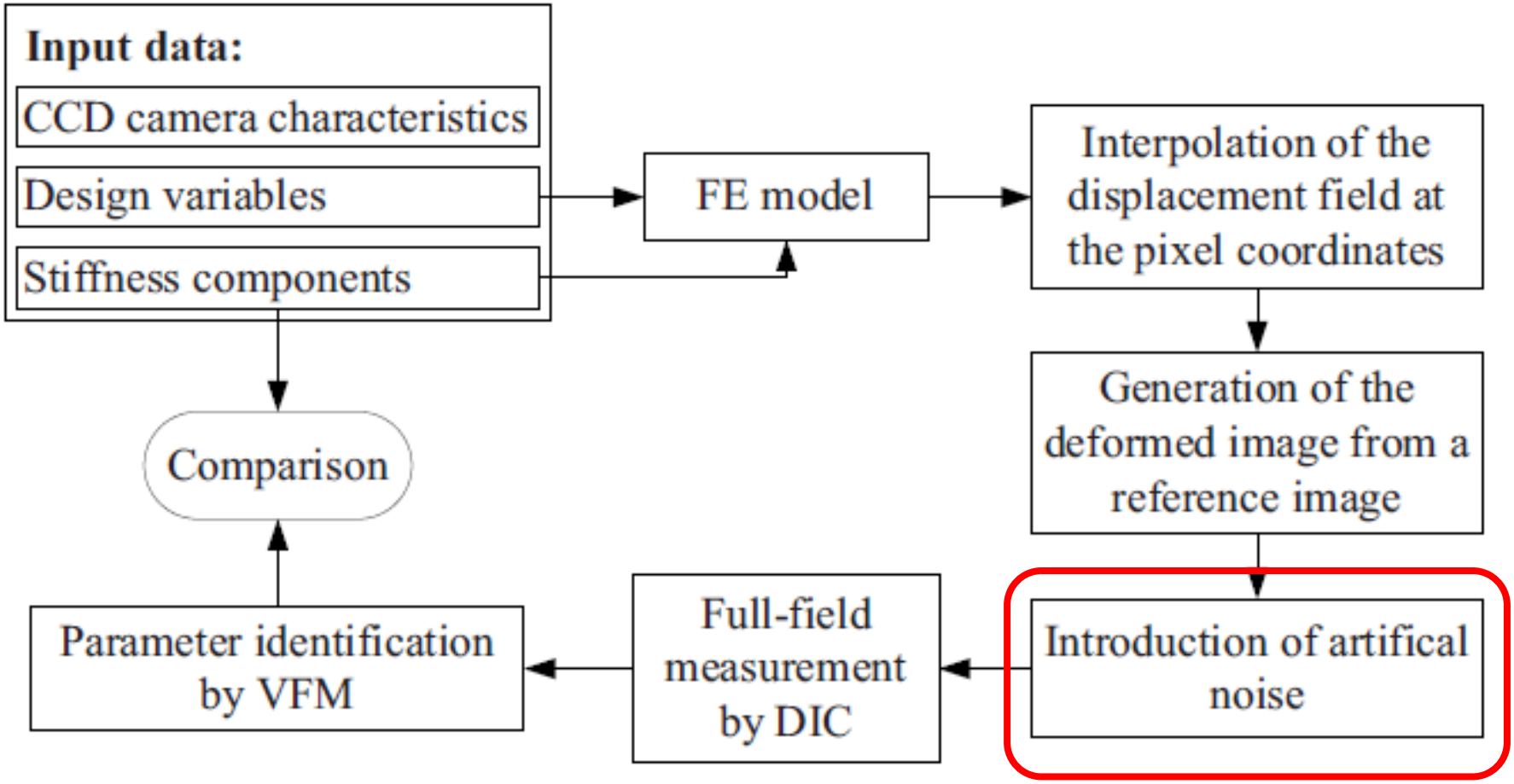
Simulate the whole identification chain



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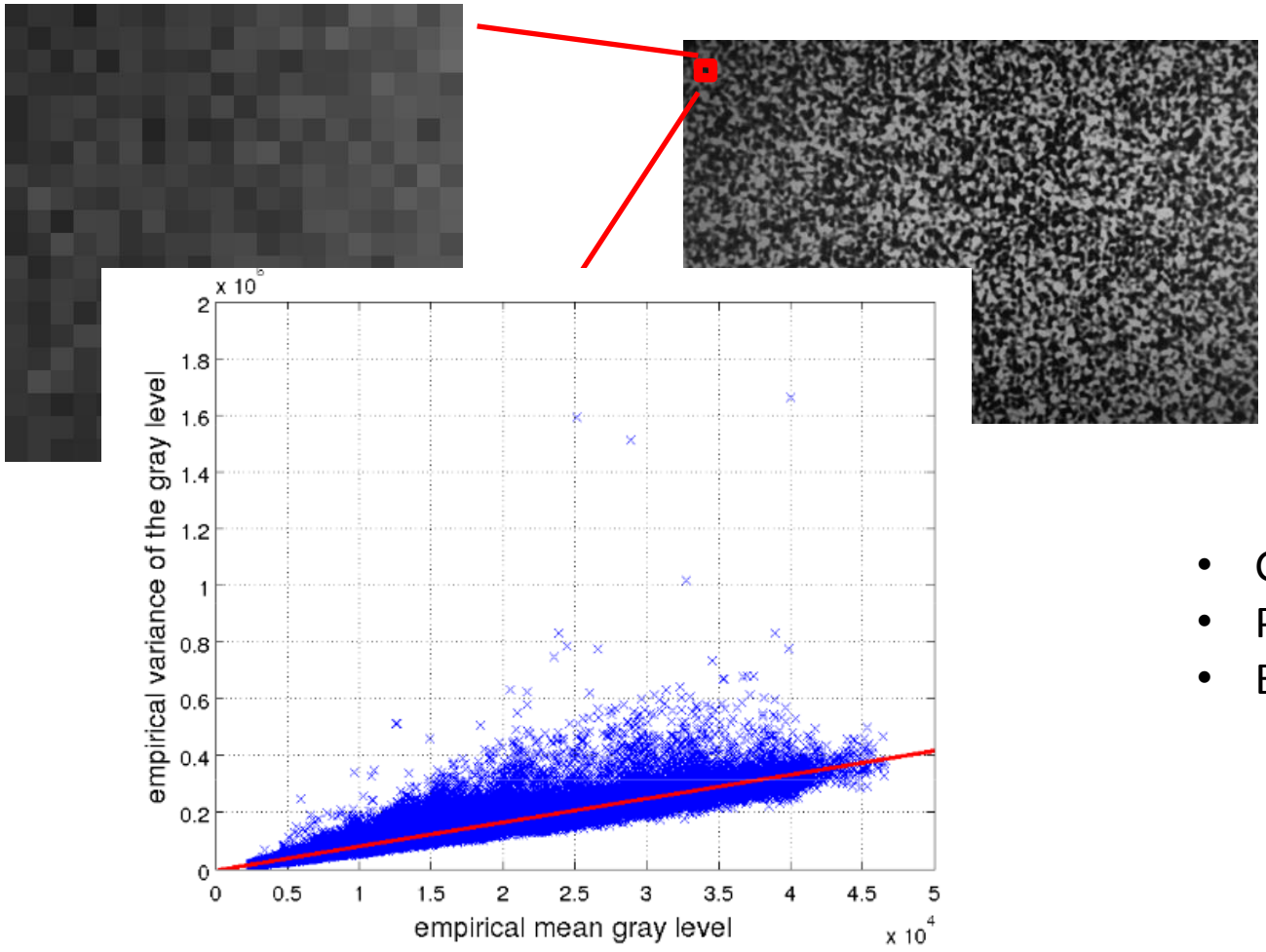
Noise …

Intensity/color fluctuation around the “actual” image intensity/color.



- Gaussian
- Poisson-Gaussian
- Extreme Value

M. Grediac and F. Sur, “Effect of sensor noise on the resolution and spatial resolution of displacement and strain maps estimated with the grid method,” Strain, vol. 50, no. 1, pp. 1–27, 2014

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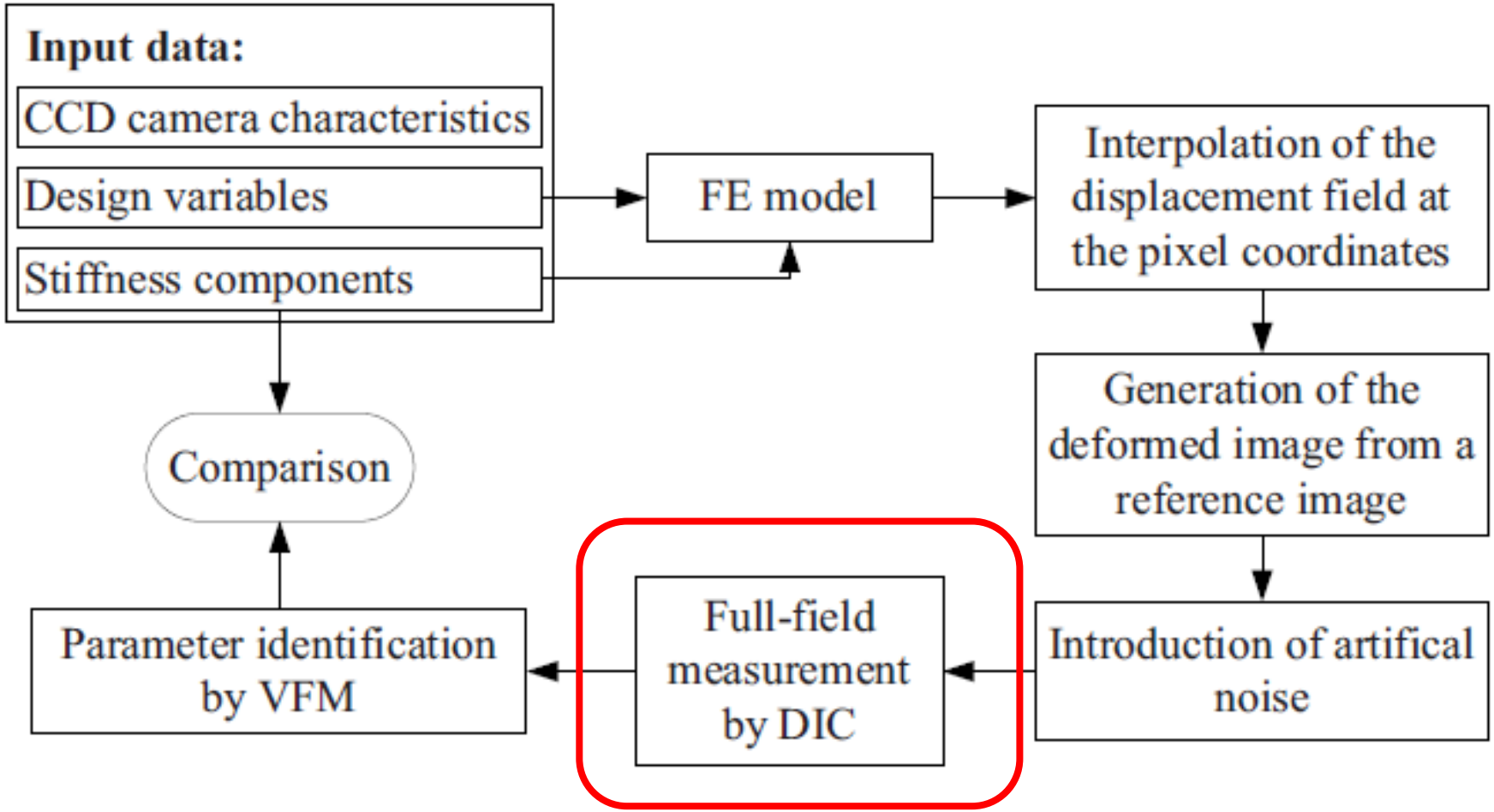
Simulate the whole identification chain



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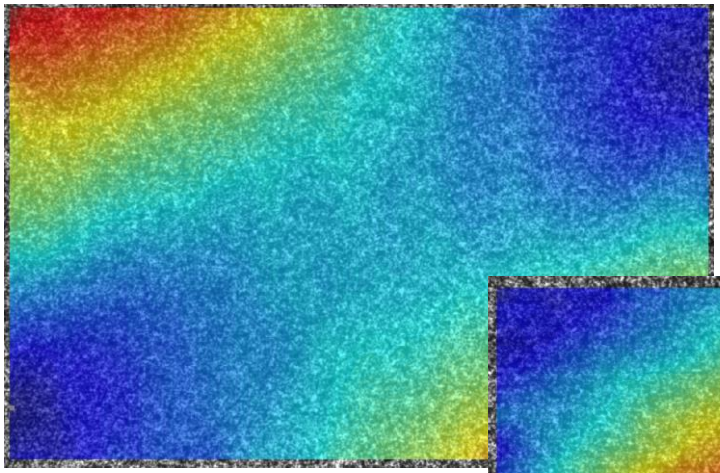
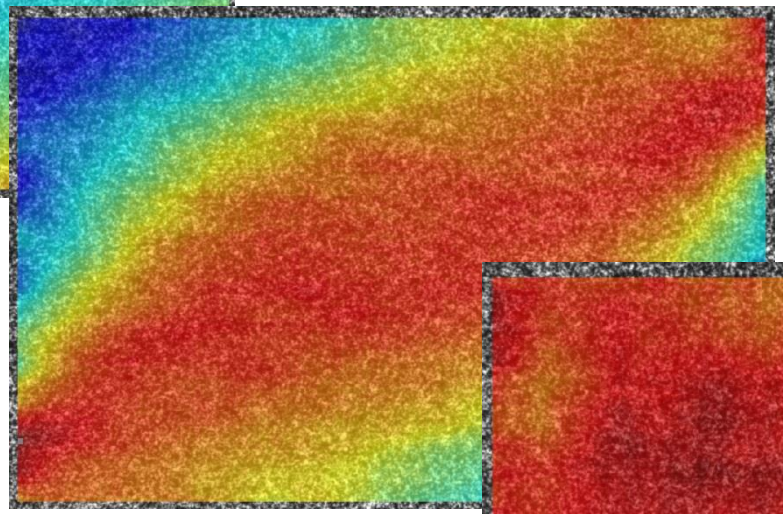
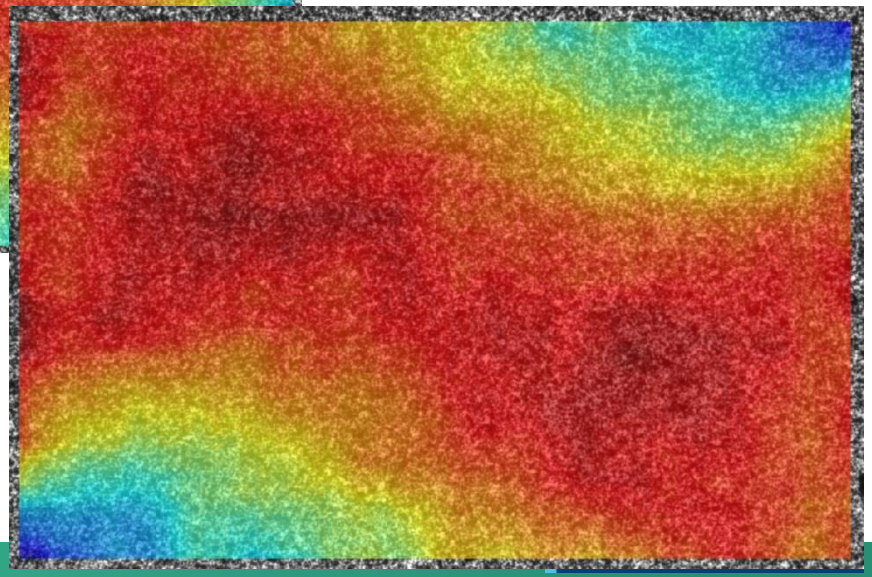
Full-field measurement by DIC



Exx

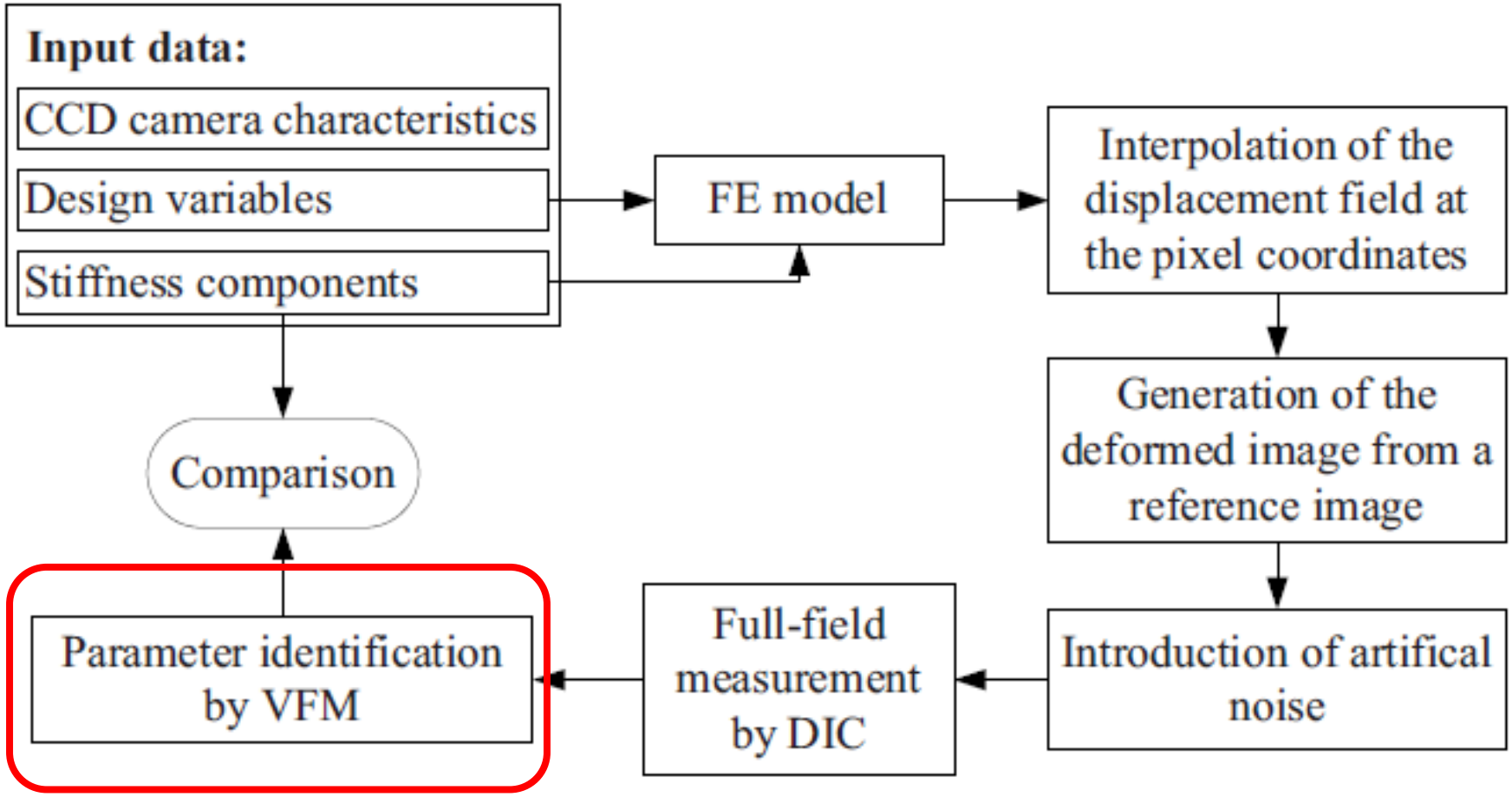


Eyy



Exy

Simulate the whole identification chain



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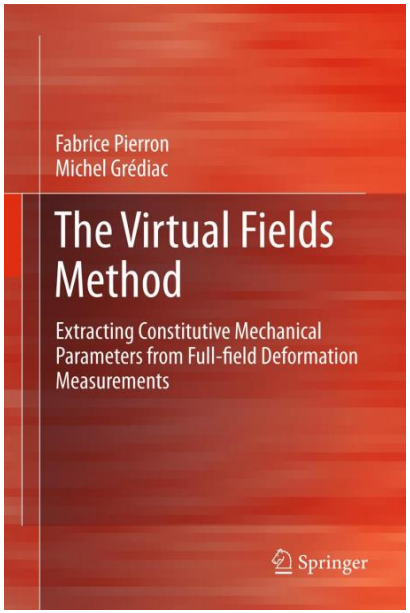
Virtual Fields Method



Based on the principle of virtual work:

$$\underbrace{-\int_V \sigma : \epsilon^* dV}_{W^*_{int}} + \underbrace{\int_S \bar{\mathbf{T}} \cdot \mathbf{u}^* dS + \int_V \mathbf{b} \cdot \mathbf{u}^* dV}_{W^*_{ext}} = \underbrace{\int_V \rho \mathbf{a} \cdot \mathbf{u}^* dV}_{W^*_{acc}} \quad \forall u^* \mathrm{KA}$$

Homogeneous linear elastic orthotropic materials

$$Q_{xx} \int_S \varepsilon_x \varepsilon_x^* dS + Q_{yy} \int_S \varepsilon_y \varepsilon_y^* dS + Q_{xy} \int_S \left(\varepsilon_x \varepsilon_y^* + \varepsilon_y \varepsilon_x^*\right) dS +$$

$$Q_{ss} \int_S \varepsilon_s \varepsilon_s^* dS = \int_{\partial S} T_x u_x^* dl + \int_{\partial S} T_y u_y^* dl$$

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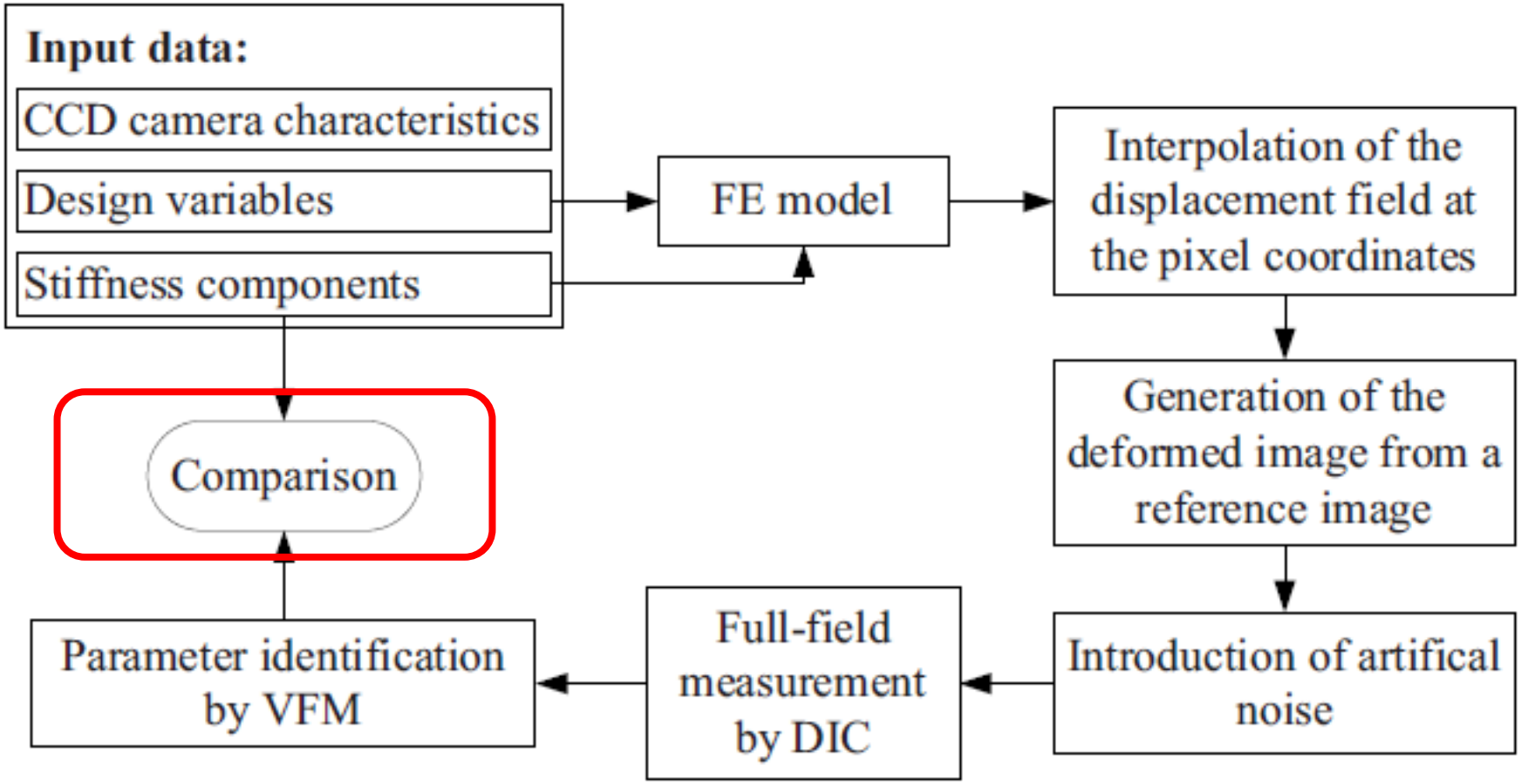
Simulate the whole identification chain



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comparison

The **identification error** is defined as

$$Err = \sqrt{\sum_{ij} w_{ij} \left(1 - \frac{Q_{ij}}{Q_{ij}^0}\right)^2}$$

with $ij = [xx, yy, xy, ss]$

Q_{ij}^0 are the reference parameters introduced in the FE model

Q_{ij} are the parameters identified with the VFM

w_{ij} is a weighting parameter

Noise introduction (random): **several** simulated experiments are repeated

$$Err = \frac{1}{N_e} \sum_{k=1}^{N_e} Err_k$$

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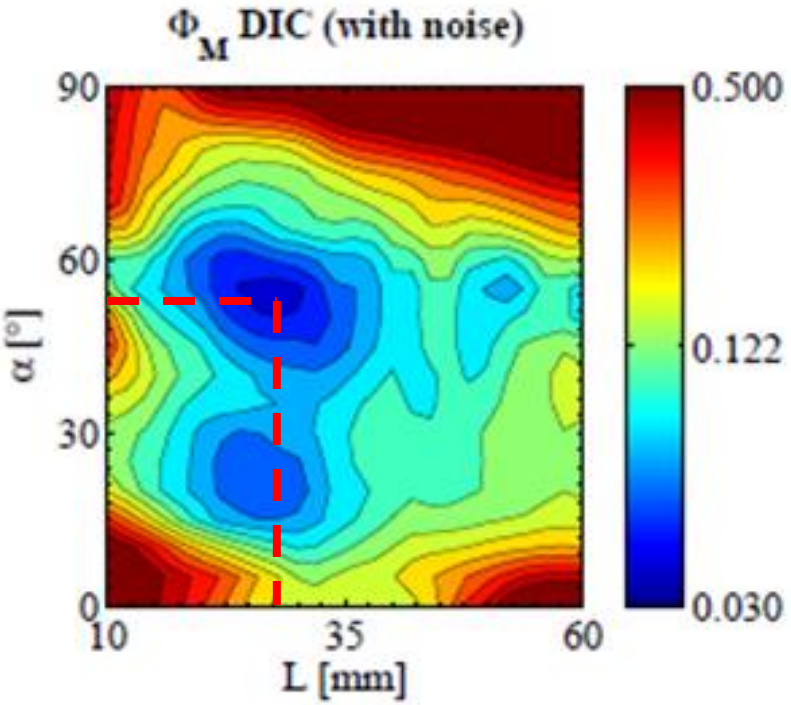
Optimization in view of TEST DESIGN

SS = 21 , VSG = 201 are FIXED
(1360x1024 ; noise: 2 grey levels; 8-bit; 20 repetitions; ΔL = 2mm ; Δα = 10°)



Optimum L = 30 mm and α = 50-60°

Rossi M., Lava P., Pierron F., Debruyne D. and Sasso M. *Effect of DIC spatial resolution, noise and interpolation error on identification results with the VFM*, submitted to Strain (2014)

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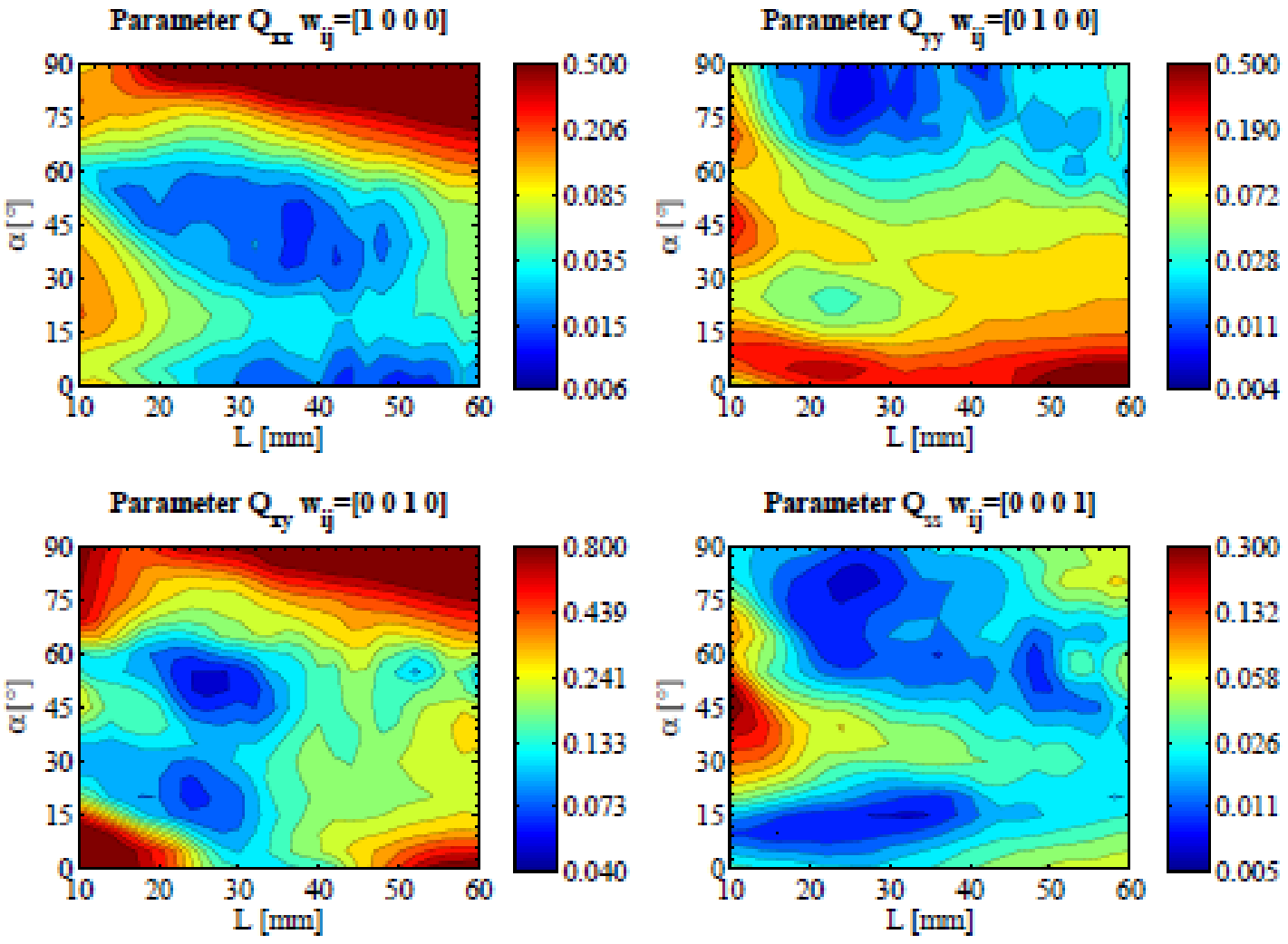
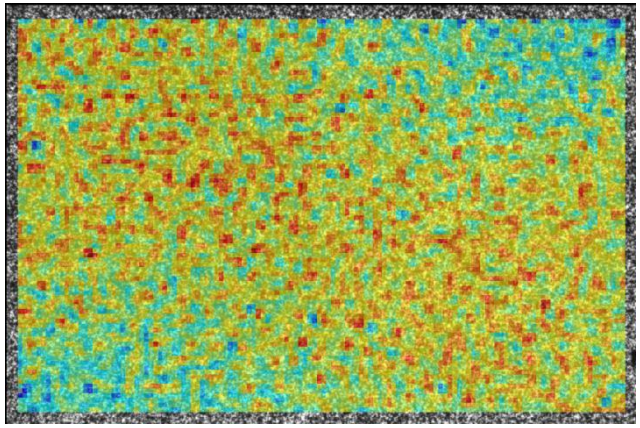
Results

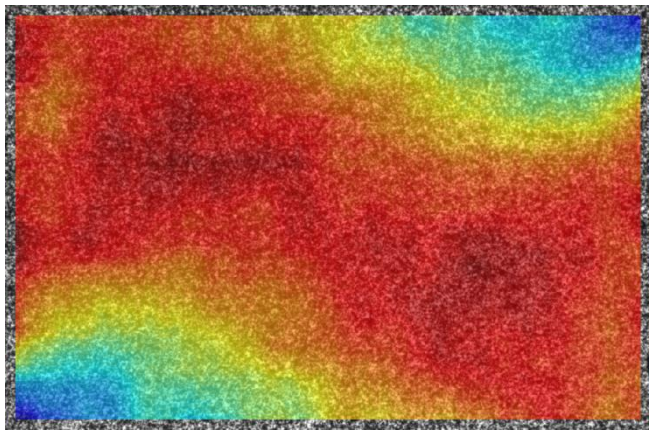

Parameter Q_{xx} w_{ij}=[1 0 0 0]
α [°]
L [mm]
0.500
0.206
0.085
0.035
0.015
0.006
Parameter Q_{yy} w_{ij}=[0 1 0 0]
α [°]
L [mm]
0.500
0.190
0.072
0.028
0.011
0.004
Parameter Q_{xy} w_{ij}=[0 0 1 0]
α [°]
L [mm]
0.800
0.439
0.241
0.133
0.073
0.040
Parameter Q_{zz} w_{ij}=[0 0 0 1]
α [°]
L [mm]
0.300
0.132
0.058
0.026
0.011
0.005

Optimization in view of Regularization

- Shear strain maps obtained by image deformation plus different levels of smoothing



VSG=5 pixels
(no smoothing)

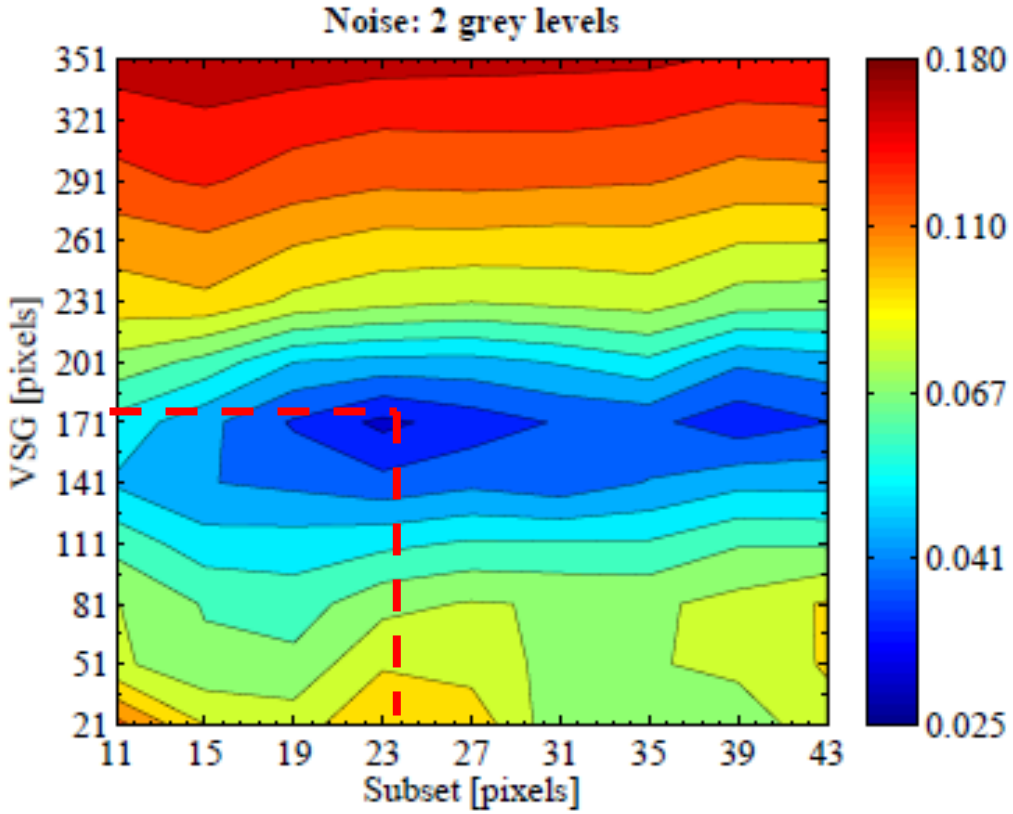


VSG=60 pixels
(local polynomial)

Which one is ‘the best’ ?

Results

L = 30 mm, α = 55° are FIXED: optimization in view of **DATA ANALYSIS**



Smoothing … but not too much

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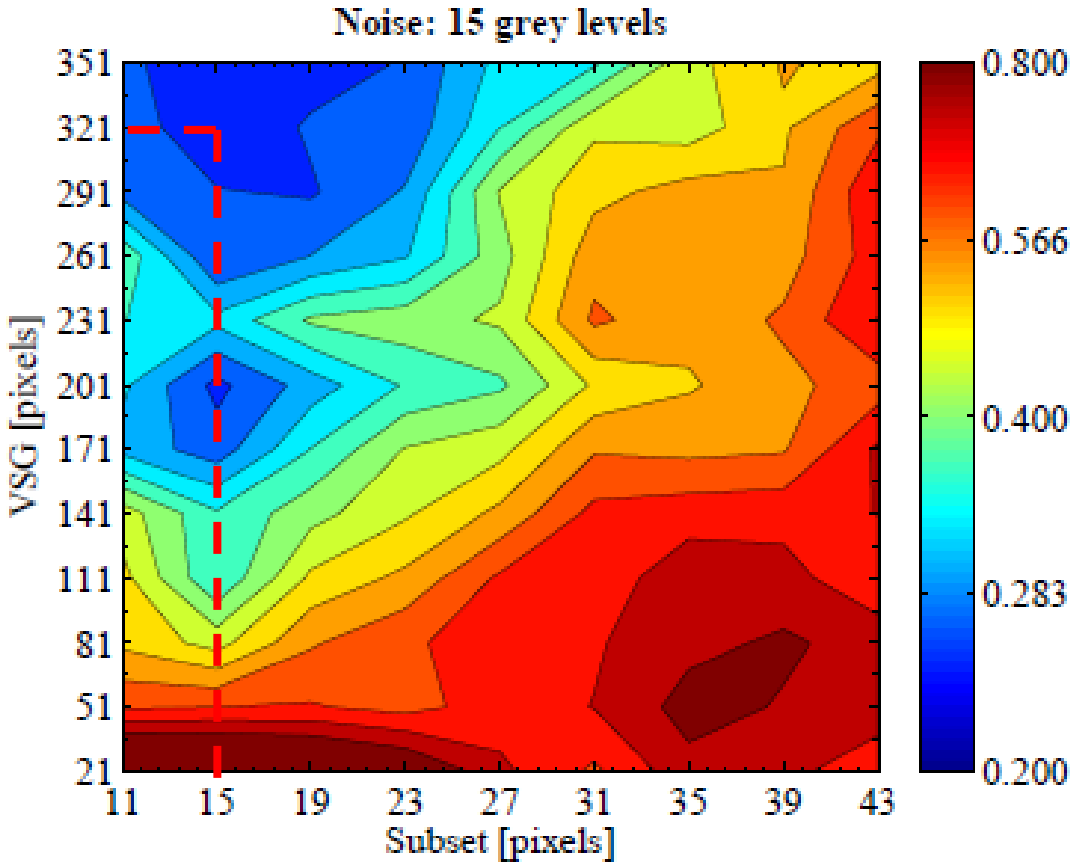

Heterogeneities … but not too much

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Conclusions

- Simulator for material identification combining DIC and VFM
- Design specimen geometries which maximize performance of DIC and VFM
- Select the optimum regularization parameters (subset, VSG, …) that minimize the error on the identified properties in function of your experimental setup (noise, lighting, …)
- Provided realistic confidence margins for the identified stiffnesses
- Applied to any material model

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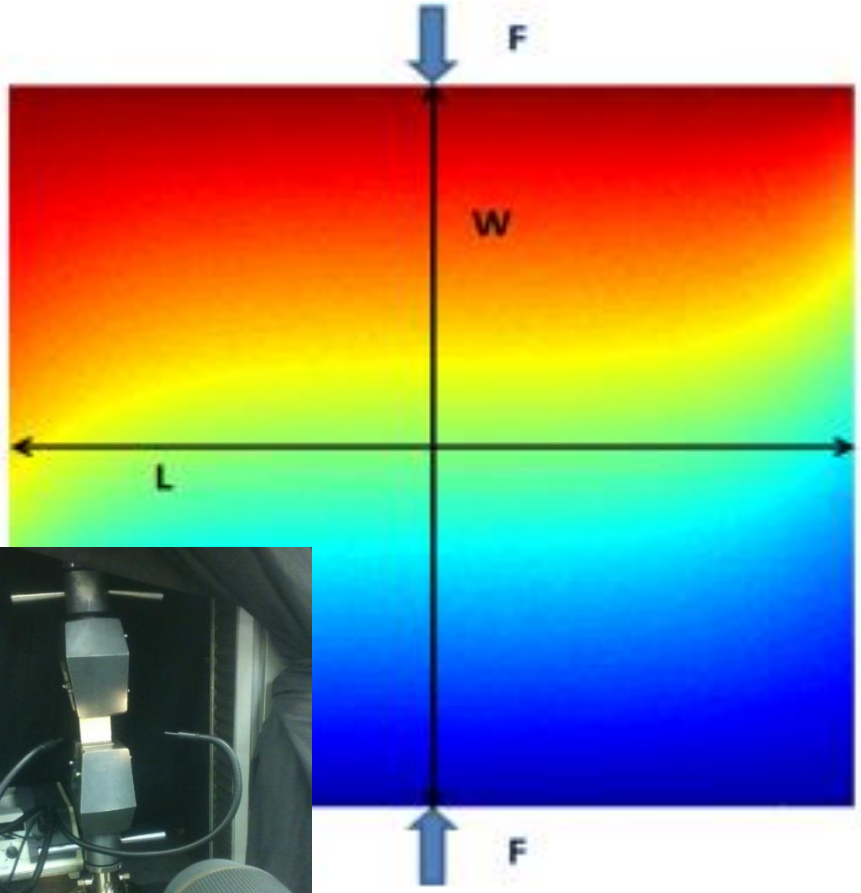
Demo of direct integration of VFM and DIC



- Glass/epoxy unidirectional composite
- Linear elastic orthotropic
- Fibre orientation: 80 degrees
- Load: 3736N
- Thickness: 1mm
- Width = length = 20mm

Reference values:

Q11 = 41000MPa
Q22 = 10300MPa
Q12=3090MPa
Q66=4000MPa

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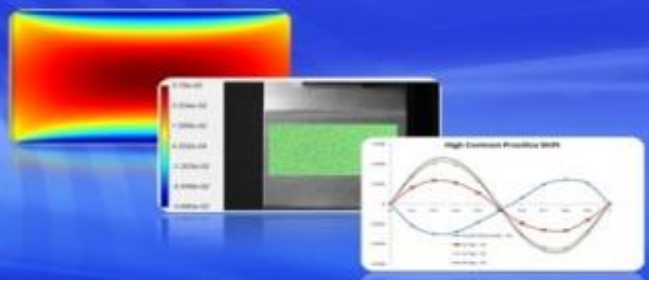
DIC course

Metrology beyond colors

January 12-16, 2015 - Ghent, Belgium



http://diccourse.matchid.org

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