Our current approach to DIC uncertainty quantification

B. Blaysat[1], F. Sur[2], M. Grédiac[1]

[1]Université Clermont Auvergne, France [2]Université de Lorraine, France

Quantities considered for this quantification:

1- **displacement resolution** or **random error**: any multiple of the std of the noise impairing the displacement maps

- = what emerges from the noise floor
- mainly due to sensor noise propagation in [1][2][3]

2- **bias** or **systematic error**:

- bias 1: interpolation bias when mapping the current image in the reference coordinate system
- bias 2: due to the matching function
- bias 3: due to the interpolation of the displacement in L-DIC

3- link between displacement resolution and bias 2/3 through the **spatial resolution**:
= « period of a sine displacement beyond which the bias affecting the displacement returned by DIC is greater than a certain value » [4]

4- **metrological efficiency indicator** for a given value of bias 2/3
=product between the displacement resolution and bias 2/3 [3]

Speckles deformed artificially are needed:

- →2017: overkill/binning, but potential errors induced while generating the deformed speckle images
- 2017→: using a Boolean model from stochastic geometry to avoid any interpolation scheme (codes/images available online soon) [5]

[1] B. Blaysat, M. Grédiac, F. Sur, *Int. Jour. Num. Meth. Eng.*, 2016
[2] B. Blaysat, M. Grédiac, F. Sur, *Exp. Mech.*, 2016
[3] M. Grédiac, B. Blaysat, F. Sur, *Exp. Mech.*, 2017, in revision
[4] L. Wittevrongel, P. Lava, S. V. Lomov, D. Debruyne, *Exp. Mech.*, 2015
[5] F. Sur, B. Blaysat, M. Grédiac, 2017, under review

Dynamic measurements of strain in soft tissues using optical method

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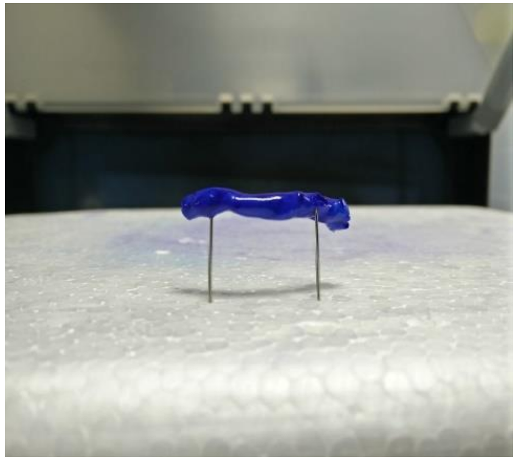
Uncertainty quantification during my experiments

Zero-strain test through a **rigid body motion (RBM)** of the object (Haddadi et al., 2008) → Any non-zero component is an **error source**



Porcine coronary coated with a dark dye

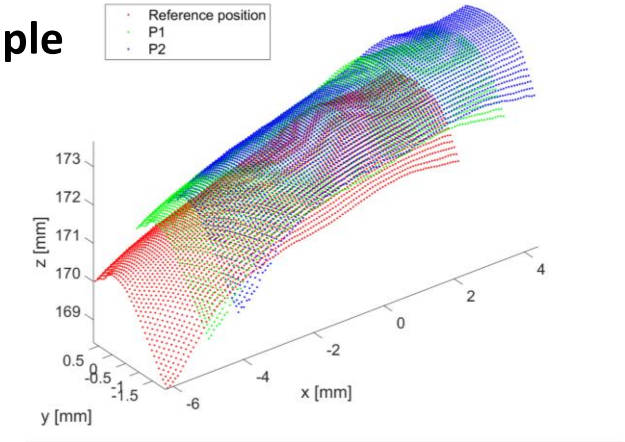
Specimen preparation

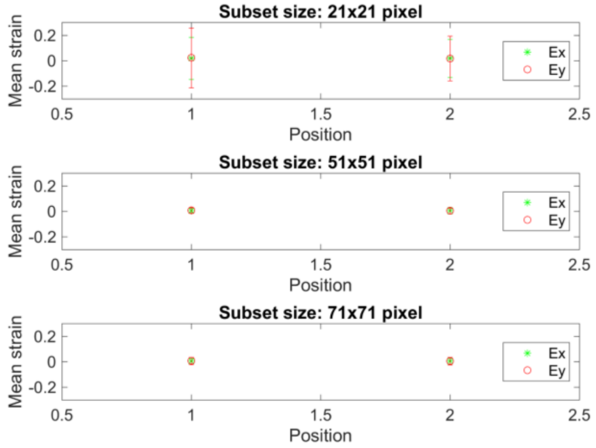
White speckle pattern applied on the sample

3D-DIC measurements

Stereo images capture

RBM test

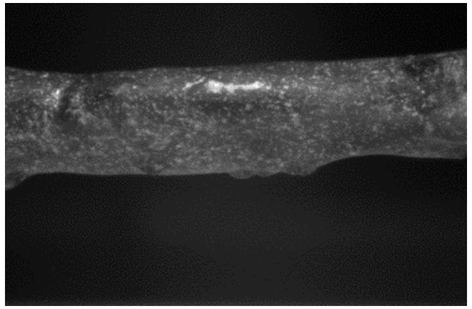


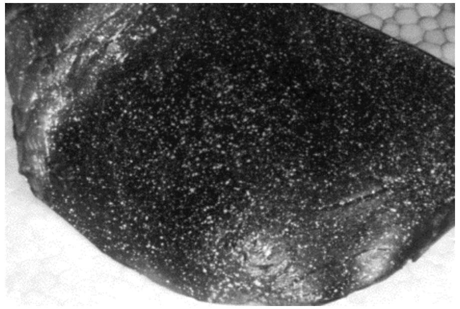


Key challenges associated with DIC measurements in soft tissues

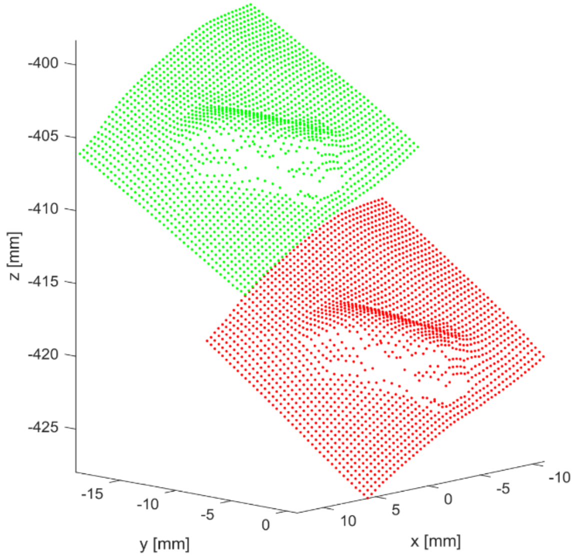
❖ Imaging and speckle pattern application issues:

- **reflection** caused by the curved surface
- **blurring** of the speckles during the deformations
- surface **moist**

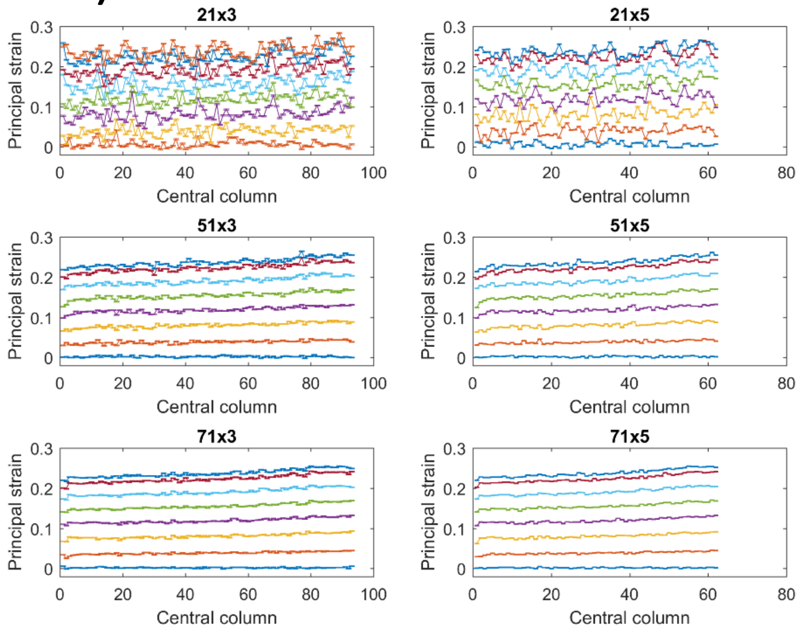




❖ Error in the 3D reconstruction and mapping of the displacements between the two images **(stereo-angle)**



❖ Optimisation of the **DIC parameters** (subset and step size)



Design level measurement of microelectronics

February 2017

Author: Dr Caroline Graham

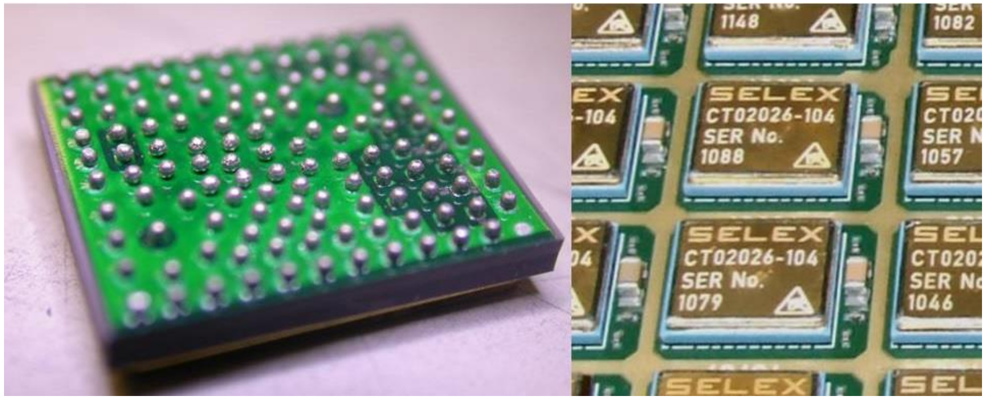
LEONARDO
AIRBORNE & SPACE SYSTEMS

Design level measurement:

- The importance of modelling and physical tests will only increase with new design innovation and a competing economic drive to consider ‘off the shelf’ parts

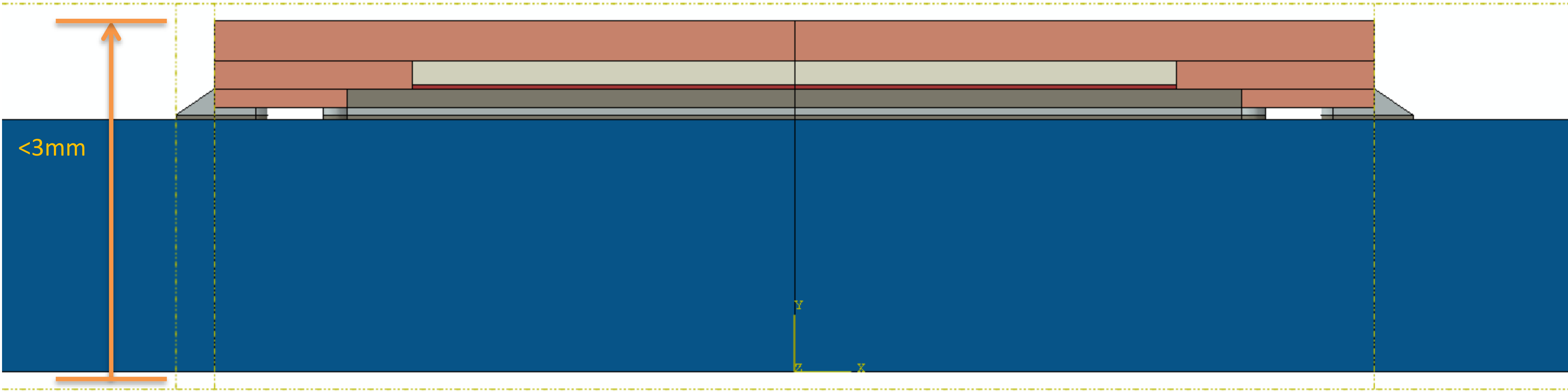
- The requirement for both design level measurement and microscale uniform material characterisation

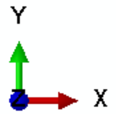
- This is not suitably addressed by any ‘British Standard’ or common measurement technique



Measurement Requirement:

- Design level measurements and microscale material characterisation tests
- Measurement method must be sensitive enough to determine thermal expansion in each material; X and Y direction, sub micrometre expansion, thermal expansion calibration
- not suitably addressed by any Standard or common measurement technique





Typical microelectronic QFN Assembly:

- Layered 'composite' component soldered to GRP Printed Circuit Board
- Highly dissimilar materials (Ceramic or Silicon, epoxy, alloy, grp)
- Highly directional PCB properties
- Non-symmetrical about design mid height
- FEA indicates high strain variance within discrete small material volumes

Dr C Graham 2017

THANK **YOU** FOR YOUR ATTENTION

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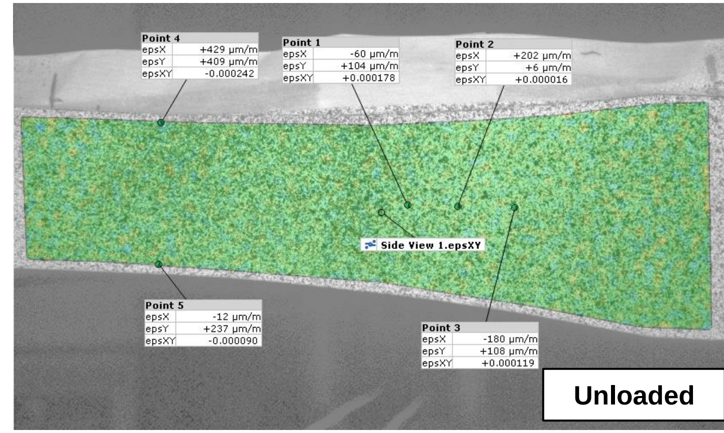
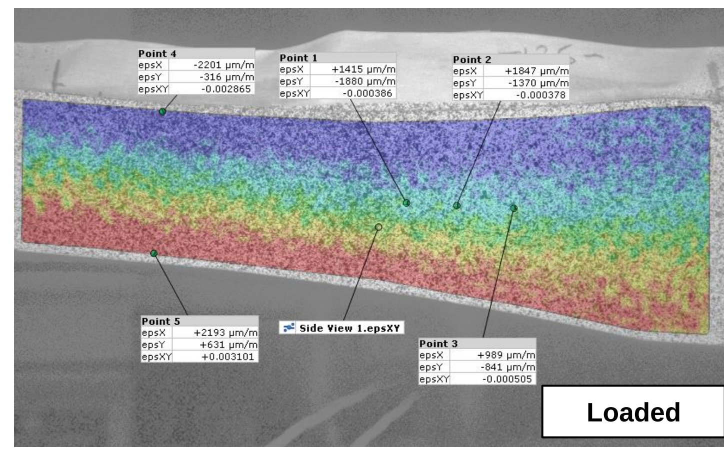
Structural Test Laboratory





<u>System</u>

- GOM 5M system for strain mapping & point tracking
- Measurement volumes up to 280x200mm

<u>Calibration</u>

- Check 'calibration deviation' and 'scale deviation'

<u>Measurement</u>

- 3 snapshots – maximum deviation
- Indication of error for a given parameter during test

<u>Limitations</u>

- Pre-test 'noise check' typical deviation ~200µƐ
- System is 'experimental'
- No consideration of systematic errors

<u>Challenges</u>

- Gaining confidence in data obtained
- Complex geometry of components
- Variation in pattern and post processing parameters
- Create internal process

DIC Uncertainty

- How can the speckling process be controlled?
- To what extent does spray paint selection affect the results?
- How can paint adhesion be guaranteed/verified?
- Is there a particular scale at which DIC is more appropriate?
- What are the implications of speckle size?
- How do lens distortions manifest within the DIC results?
- How sensitive is 2D DIC to camera position?
- What results are most suitable for comparison between DIC and FE?
- At what point can DIC be assumed unsuitable when testing ductile materials?
- How can an accuracy be determined for DIC results?
- How can an appropriate facet size be quickly selected?

7 Steps to Measurement Uncertainty

Erwin Hack, Empa, Dübendorf, Switzerland

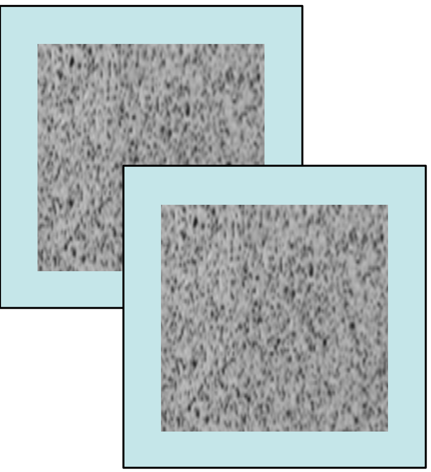
Empa Materials Science and Technology

1. Definition of measurand
   - Importance is often underestimated
2. Specification of target uncertainty
3. Modelling the measurement chain
   - Modularization (e.g. calibration, object, experimental set-up)
   - Analytical or numerical modelling (e.g. Monte Carlo)
4. Identification of input and influence parameters
5. Quantification of the standard uncertainties
   - Type A and B (according to GUM [1])
6. Calculation of the combined uncertainty
   - Using the model defined before
7. Re-loop or Report
   - Comparison to target specification

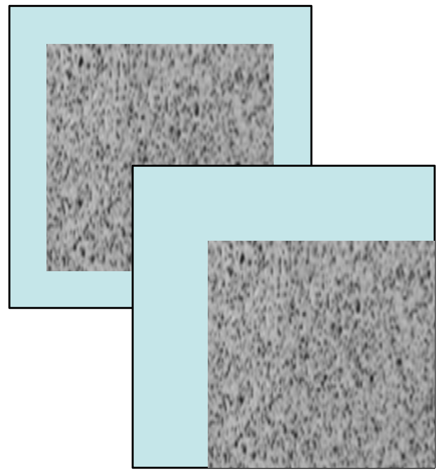
[1] GUM: Guide to the Expression of Uncertainty in Measurement, JCGM 100:2008
Supplement 1 to the GUM — Propagation of distributions using a Monte Carlo method, JCGM 101:2008
Supplement 2 to the GUM — Extension to any number of output quantities JCGM 102:2011

DIC-measured strain for known (imposed) scenarios:

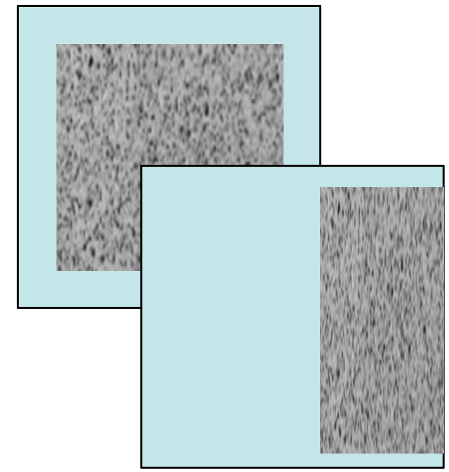
0 displacement
0 strain

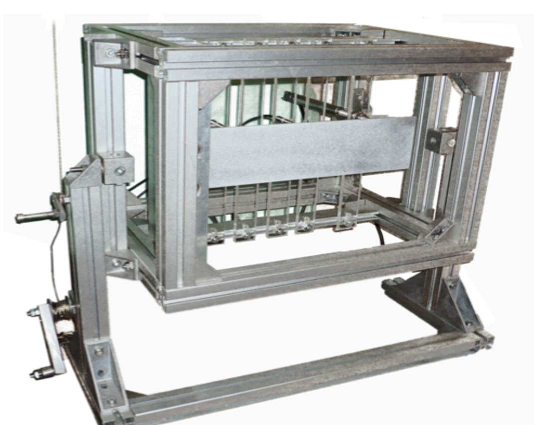


Known translation/rotation
0 strain



Known translation/rotation
Known strain





Quantification of uncertainties in DIC

M.Palanca – M.L. Ruspi – L. Cristofolini

Metrics:

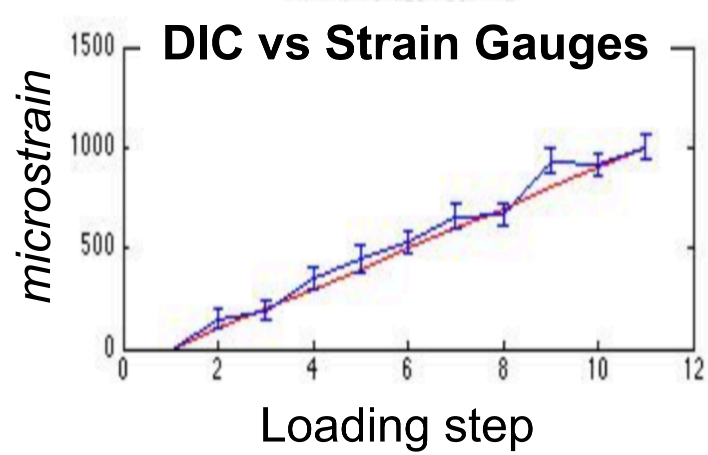
0 displacement *0 strain*	*Known translation/rotation* *0 strain*	*Known translation/rotation* *Known strain*

- Strain accuracy:
  - Average ≠ 0
- Strain precision (standard deviation)
  - Standard deviation around nominal value

- Comparison with beam theory
- Comparison with strain gauges

Results with optimal HW & SW settings:

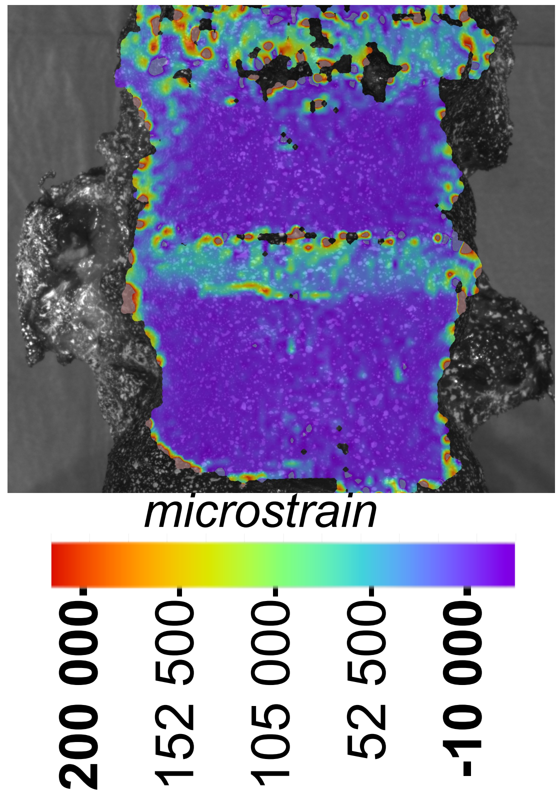
- Accuracy = 10 microstrain
- Precision = 110 microstrain



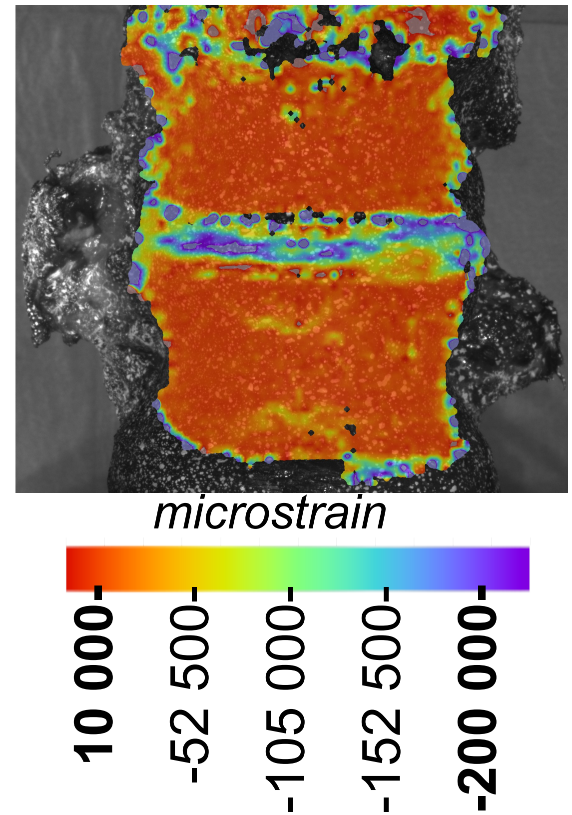
Ready for application to human spine

M.Palanca – M.L. Ruspi – L. Cristofolini

MAX PRINCIPAL STRAIN



MIN PRINCIPAL STRAIN



Aims:
Strain measurements on vertebrae and intervertebral discs

Comparison of **painting** lining methods for **historic house** environments

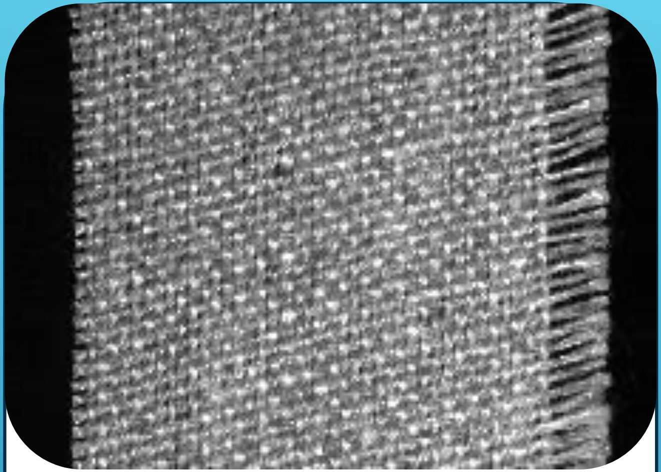
Vladimir Vilde

UCL

LaVision
FOCUS ON IMAGING

EPSRC
Pioneering research and skills

ENGLISH HERITAGE



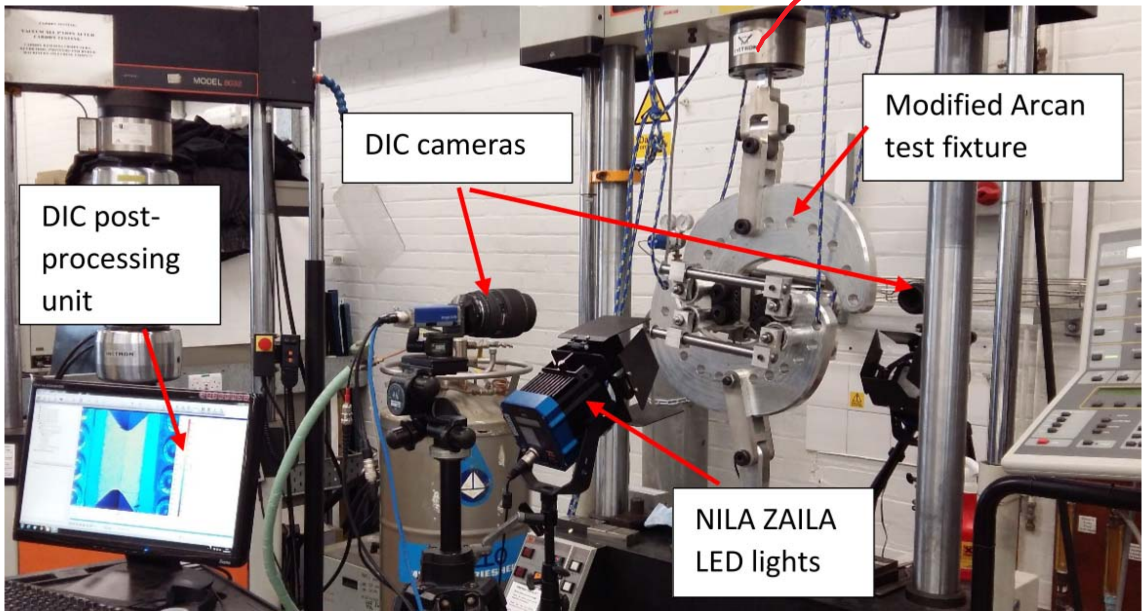
Natural pattern
&
Coloured surfaces

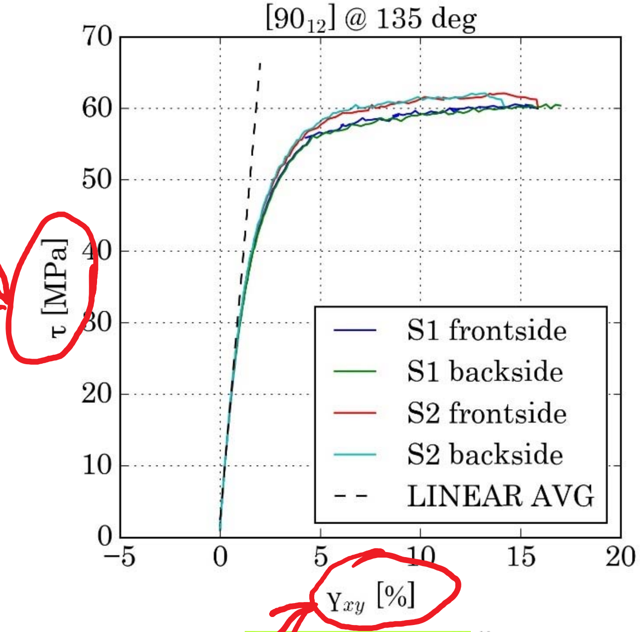
Uncontrolled
Built heritage

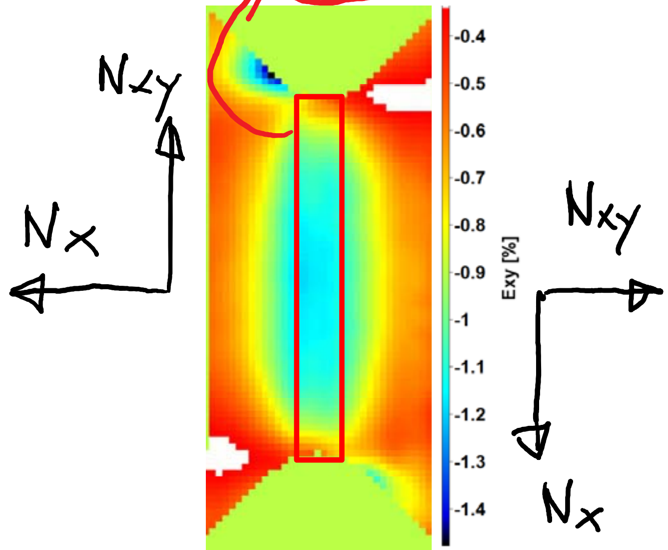
Pro vs consumer
RGB and access

UNIVERSITY OF Southampton

The Experiment

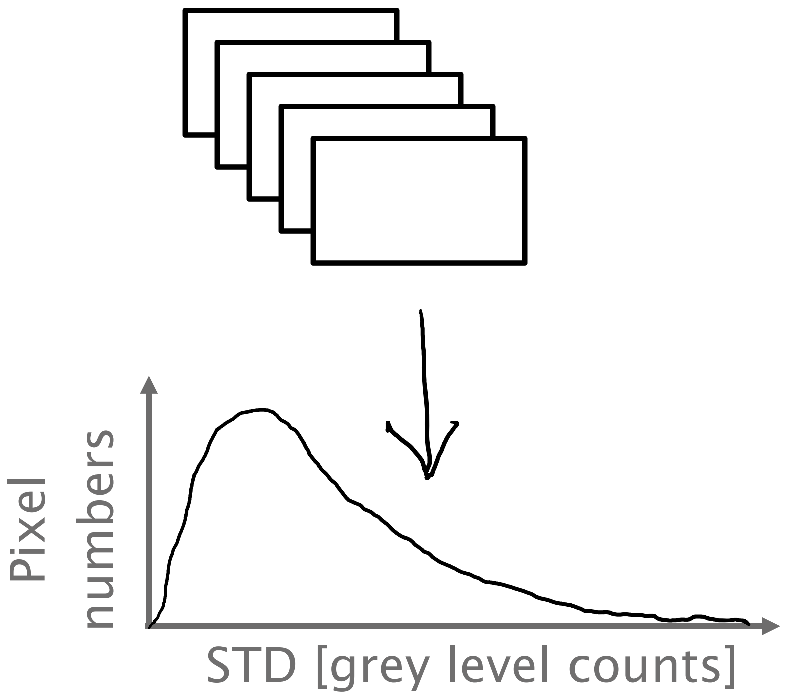




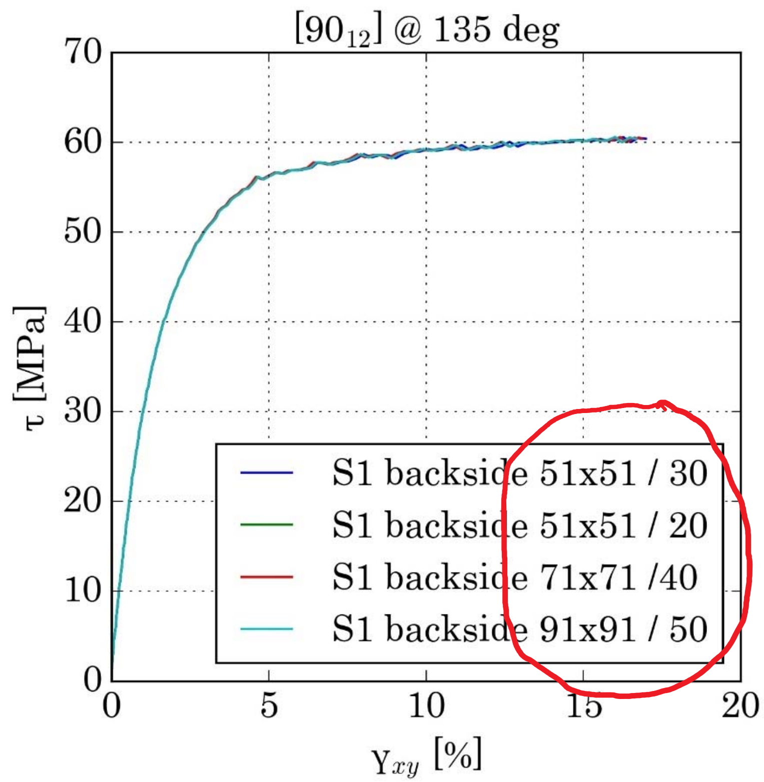


Managing Uncertainty

Histogram of std on grey scale level over 5 static images



Sensitivity of results to subset and overlap choice



DIC Measurements of the Human Heart during Cardiopulmonary Bypass Surgery

Mikko Hokka and Sven Curtze

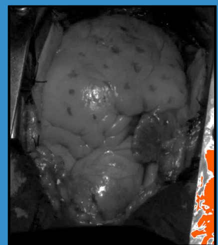
Tampere University of Technology,
Department of Materials Science

cardiomeDIC
lights up hearts

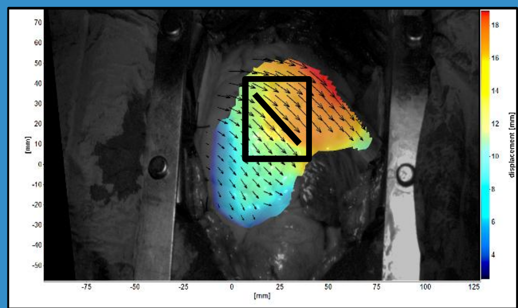
Measurement setup

- 2x 5MPIX Elite cameras
- ~1.5 m distance
- Adjustments not possible
- Post calibration

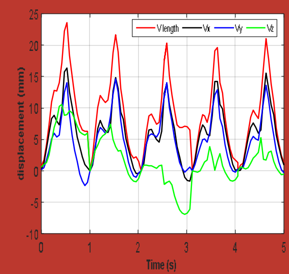
Data Processing

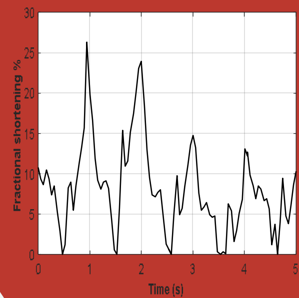


- 2D or 3D DIC calculations using Davis 8.x
- Sum of Differentials



Output



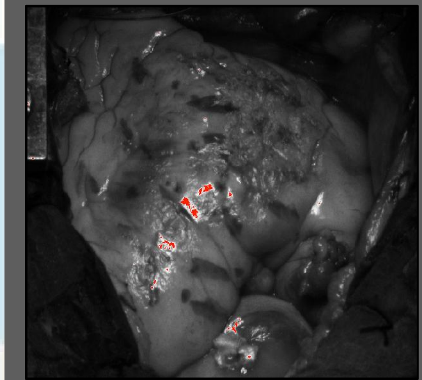


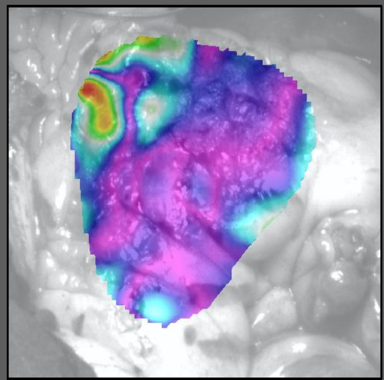
- Various parameters to describe functioning of the Right Ventricle
- Changes can be detected
- Patient monitoring

Uncertainty Quantification

cardiomeDIC
lights up hearts

Uncertainties in the raw data





- Poor contrast patterns, glare problems and other experimental issues
- Qualitative estimation of errors based on stereo reconstruction error (3D) and correlation values (2D)

Uncertainties in the final results

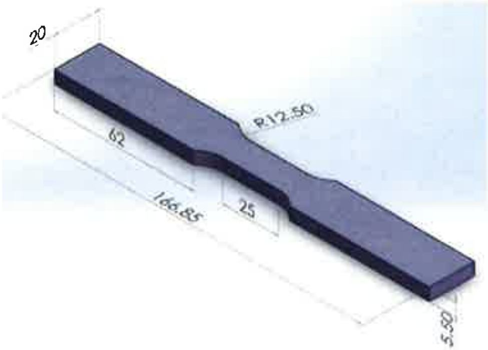
- …We are working on it…
- Currently only statistical methods, scatter plots, mean values, and standard deviations are being evaluated.
- Need new ideas!

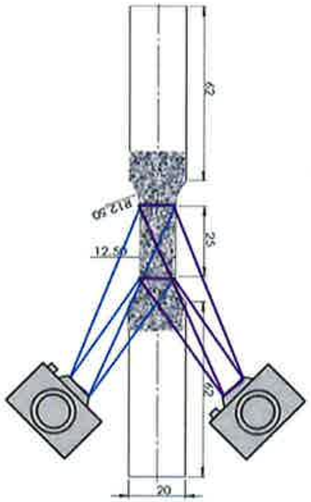
To Identify 1st Coating Crack

AkzoNobel

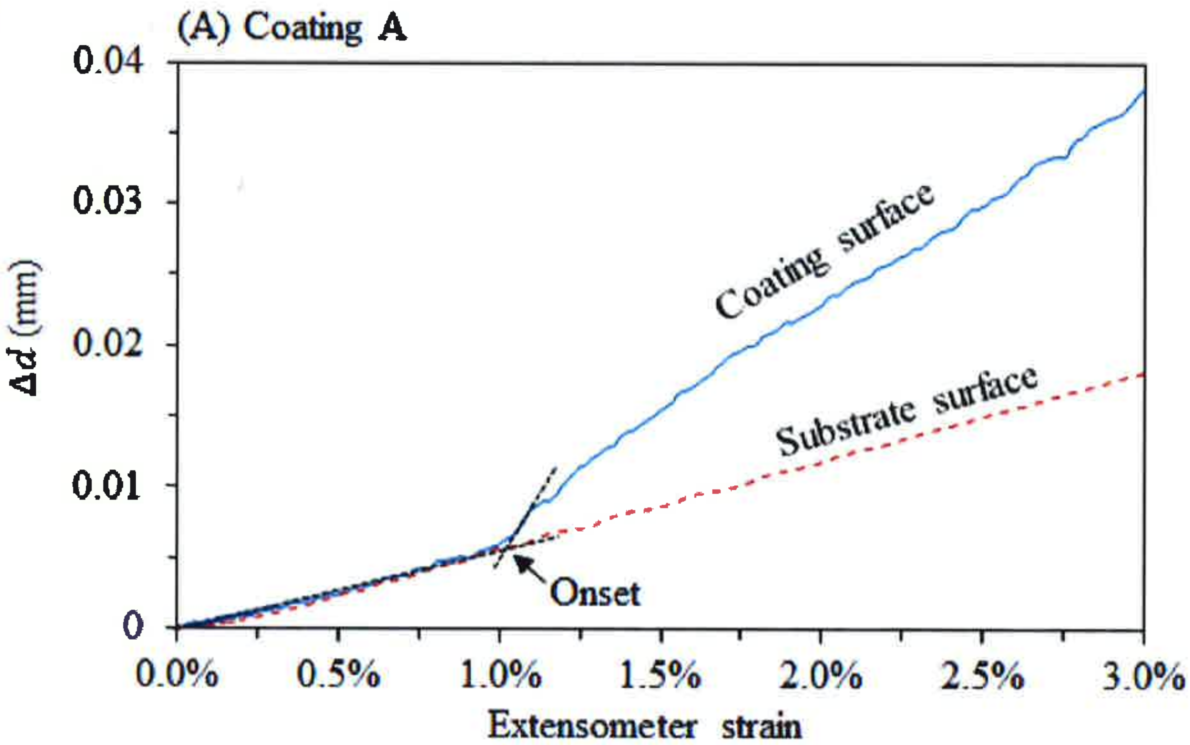
Fangming Zhao

- Steel/Primer coating/DIC painting





Change of displacement across the first coating crack

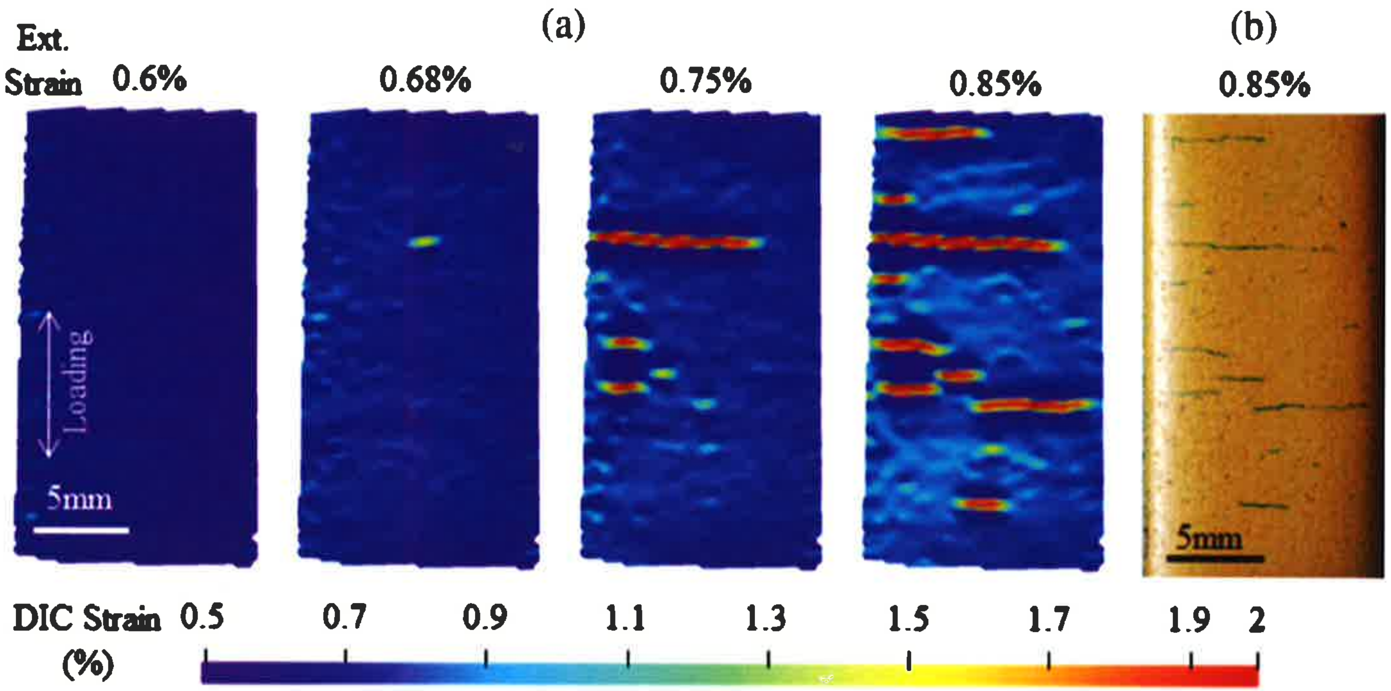


T. Wu, P.E. Irving, D. Ayre, G. Dell'Anno, P. Jackson, F. Zhao Engineering Fracture Mechanics 159 (2016) 1-15

AkzoNobel

To Measure Strain to 1st Coating

- Local strain at 1st coating crack (DIC images)



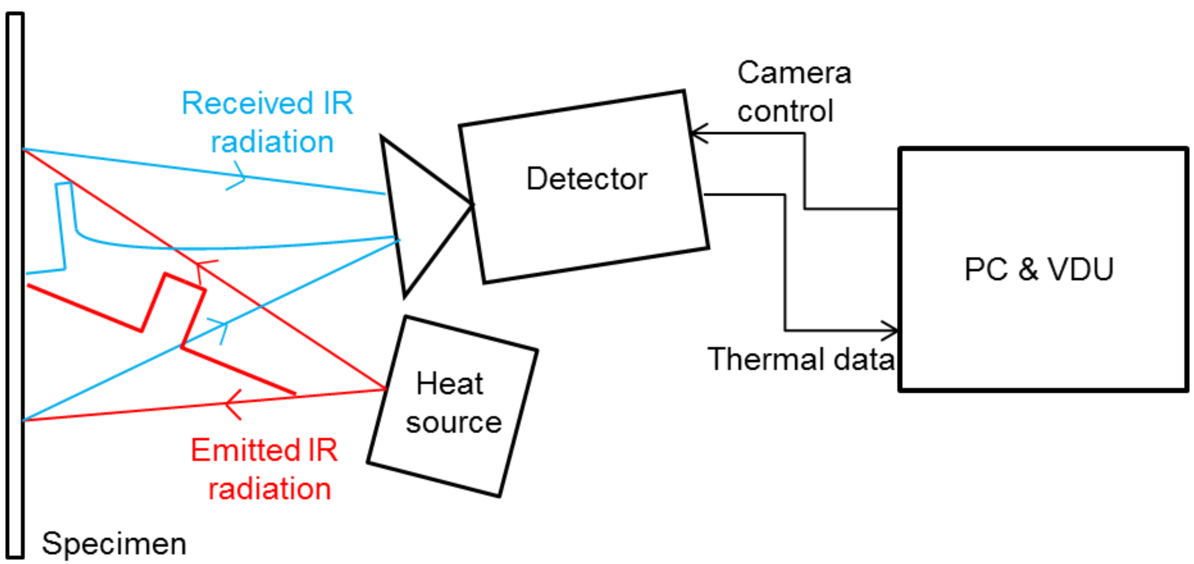
- Unclear points
  - Global strain (0.68%, extensometer) vs local strain (1.21%, DIC)
  - Effects of DIC painting

UNIVERSITY OF Southampton

Project

- NDT of composite materials
- Not currently using DIC
- Primarily used pulsed thermography
    - Camera flash to generate heat pulse to heat specimen
    - IR camera used to measure and record thermal decay
    - Decay of defective and non defective areas not equal

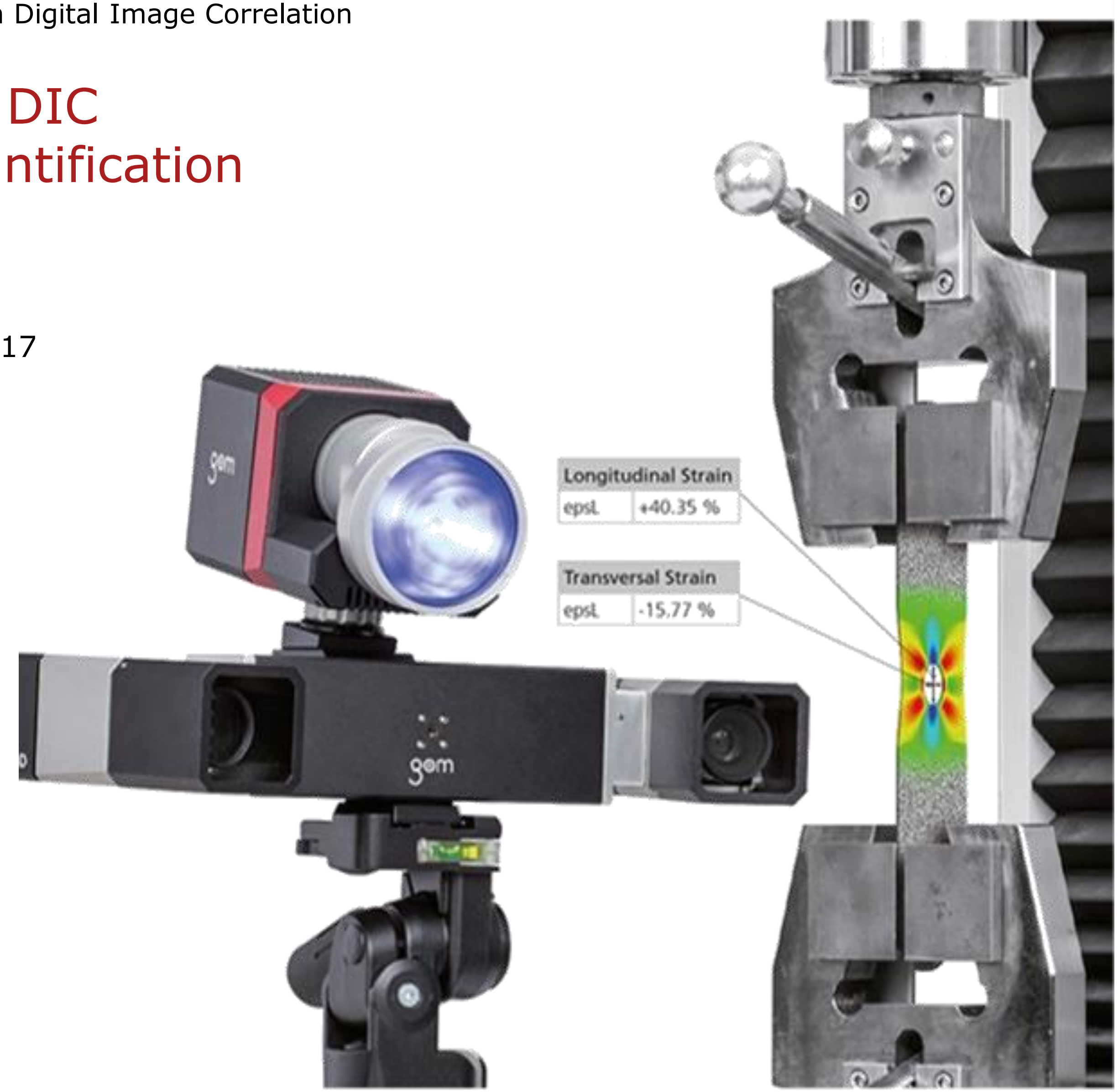
Experimental Setup



Uncertainty Quantification in Digital Image Correlation

How GOM train DIC uncertainty quantification

Amy Johnson | 22.02.2017



Noise checks on a stationary object

Method

- Set the system up ready for measurement
- Position part to be measured
- Capture a series of 10+ images statically
- Check component for displacement

This Checks

- Optical set-up - Lens focus, camera angle, depth of field etc
- Calibration
- Lighting
- Pattern quality