Our current approach to DIC uncertainty quantification

B. Blaysat¹, F. Sur², M. Grédiac¹

¹Université Clermont Auvergne, France ²Université 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]

Dynamic measurements of strain in soft tissues using optical method

Paolo Ferraiuoli, PhD student
Mathematical Modelling in Medicine (MMM) group
Department of Infection, Immunity & Cardiovascular Disease
Faculty of Medicine, Dentistry and Health

(p.ferraiuoli@sheffield.ac.uk)
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

Stereo images capture

White speckle pattern applied on the sample

3D-DIC measurements

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
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
THANK YOU FOR YOUR ATTENTION
Structural Test Laboratory

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

Calibration
- Check ‘calibration deviation’ and ‘scale deviation’

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

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

Challenges
- 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

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
# Quantification of uncertainties in DIC

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

## DIC-measured strain for known (imposed) scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 displacement</td>
<td>0</td>
</tr>
<tr>
<td>Known translation/rotation</td>
<td>0</td>
</tr>
<tr>
<td>Known strain</td>
<td></td>
</tr>
</tbody>
</table>

![DIC-measured strain images](image-url)
Quantification of uncertainties in DIC
M.Palanca – M.L. Ruspi – L. Cristofolini

**Metrics:**

<table>
<thead>
<tr>
<th>0 displacement</th>
<th>Known translation/rotation</th>
<th>Known translation/rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 strain</td>
<td>0 strain</td>
<td>Known strain</td>
</tr>
</tbody>
</table>

- 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
Aims: Strain measurements on vertebrae and intervertebral discs
Comparison of painting lining methods for historic house environments

Vladimir Vilde
Natural pattern & Coloured surfaces

Uncontrolled Built heritage

Pro vs consumer RGB and access
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

**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

---

DIC image and graph with measurements and parameters.
Uncertainty Quantification

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

- Steel/Primer coating/DIC painting

Change of displacement across the first coating crack

To Measure Strain to 1st Coating

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

![DIC images showing strain levels](image)

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