Practical assessment of DIC uncertainties in view of FE model validation

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Abstract. The validation of structural models using Digital Image Correlation (DIC) is an emerging field. Using a DIC Digital Twin of the DIC experiments to create validation maps, it is possible to account for most of the systematic errors like limited spatial resolution or interpolation bias. The validation residuals then need to be compared to the random errors of the DIC set-up to decide whether or not there is still a model error present. This paper proposes a practical assessment of DIC errors and illustrates the remaining challenges, particularly for small elastic strains.

Possible Sessions: Model validation, Optical and DIC Techniques

Introduction

Digital Image Correlation (DIC) is an experimental technique used to measure full-field surface deformation using digital cameras. The data-rich nature of the resulting deformation fields makes it an ideal tool for detailed experimental validation of structural mechanical models, most often obtained with the finite element (FE) method. There is however limited literature on this topic. A corpus of work was published by the research group led by E.A. Patterson [1] using low pass spatial filtering in the form of so-called shape descriptors (polynomials of different sorts). The DIC uncertainties are simply approached through a bending test on a beam. This suffers from the fact that it does not include the complex uncertainty quantification (UQ) arising from the highly nonlinear correlation algorithm. In particular, by using a bending test that leads to linear displacement distributions through the width, it ignores the interplay between the spatial frequencies in the model and the limited spatial resolution of DIC. A more advanced approach has been recently proposed, the so-called 'DIC-levelling' method, which uses the model displacements to create a Digital Twin (DT) by numerically deforming the speckle images [2]. These images can then be processed with the same DIC parameters as the experiment to allow for a direct comparison in the form of a validation map. Although very recent, this approach has already been confirmed as an essential tool for model validation by a few studies [3, 4]. However, a common feature of these articles, all dealing with large strain plasticity, is that they do not focus on detailed investigations of the errors remaining in the validation maps, and how the different sources of DIC uncertainty may or may not affect these maps. DIC uncertainties have been extensively studied in detail in the past [5], but not with a view to finite element model validation. The objective of the present paper is to propose a practical methodology to address DIC uncertainties in the context of FE model validation with DIC measurements.

DIC uncertainties

Table 1 lists the main uncertainties associated with DIC.

Ref.	Name	Nature	Covered by
1	Camera noise	Random	Stationary images
2	Noise induced bias	Random*	Stationary images
3	Interpolation bias	Random*	Digital twin
4	Pattern induced bias	Random*	Digital twin
5	Intensity digitization bias	Random	Stationary images
6	Spatial filtering	Systematic	Digital twin
7	Specular reflection	Random*	Polarized light
8	Heat haze	Random*	Nothing
9	Calibration errors	Systematic	Rigid body movements
10	Camera heating	Systematic	Nothing (let camera heat up before test)

* deterministic but too complex, treated as random in practice

The digital twin approach deals with interpolation bias, pattern induced bias and limited spatial resolution [2]. Therefore, this will not be studied here. We will concentrate on the remaining errors. Most of these are random errors that can be evaluated using stationary images, namely: Camera noise (CN), Noise induced bias (NIB) and Intensity digitization bias (IDB). CN arises from the random grey level noise at each pixel which creates a random deformation noise when processed through DIC [6]. NIB is generated by the interplay between camera noise and interpolation [6]. Digitization bias [5] arises from the digitization of the camera signal and depends on the bit depth used. The calibration errors have not been studied here and will be the object of a separate study using rigid body motion. The remaining ones (7, 8 and 10) are errors that can only be minimized at setup stage.

To study the above, a series of 100 stationary images were experimentally recorded on a glass/epoxy specimen with two asymmetric notches. Displacement and strains were computed using the first image as reference and all others as deformed. The same was repeated by using the average of the 100 images as reference. This average was also used to simulate camera noise

Results

First, it was found that there existed a temporal bias caused by the fact that the noise copy of the reference image is present on all maps. Fig. 1 shows a comparison between the simulation and the experimental noise on strain. The temporal bias is of the same order of magnitude as the standard deviation (noise floor) and has to be considered in the validation maps. Also, both random and bias errors are spatially dependent because of local changes of contrast or NIB. The experimental maps are well reproduced by the simulated, showing that we have captured the main sources of errors in this example. The paper will present more results on the effects of IDB, specular reflection and show the benefits of using an averaged imaged.

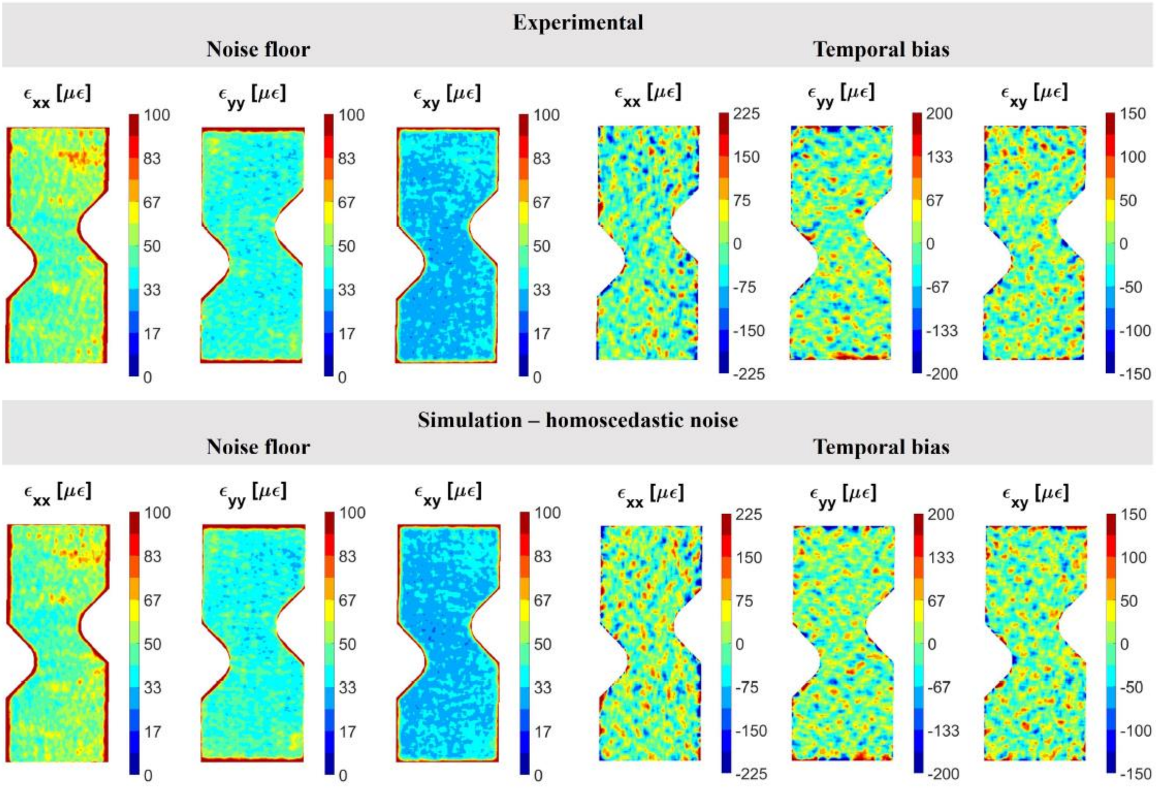

Figure 1 – Comparison between experimental and simulated DIC errors

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