Evaluation of sensitivity-based virtual fields for non-linear parameter identification including DIC filtering effects

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Abstract. Recently, the issue of automatically defining virtual fields for non-linear constitutive models has been resolved [1], relying on a new sensitivity-based approach hereby reducing the influence of noise on the parameter identification. These new set of fields act as weighting factors in the identification process emphasizing the impact of measurement regions with high signal to noise ratios. Conclusions in [1] were drawn based on a numerical example involving small strain plasticity. In this presentation, the performance of these newly defined fields is studied when applied to digital image correlation (DIC) measurement data, hereby including the DIC filtering effects through synthetic image deformation [2]. Results are presented for both large strain isotropic plasticity and hyperelastic material models .

Theoretical development

For a detailed theoretical development of the sensitivity-based VFs the user is referred to [1]. In summary, the idea behind the proposed approach is that these fields will emphasize regions that carry the most information about the involved constitutive parameters and their time evolution. Each model parameter *i* is perturbated in order to determine intrinsic parameter sensitivity $\delta\boldsymbol{\sigma}^{(i)}(\boldsymbol{\varepsilon},\boldsymbol{X},t)$and incremental sensitivity $\delta\tilde{\boldsymbol{\sigma}}^{(i)}(\boldsymbol{\varepsilon},\boldsymbol{X},t)$ maps, with ***X*** the vector of the model parameters and *t* the time step. The virtual displacement ***u**** are then determined from these maps by imposing a virtual mesh on the data point cloud. Next, when the equations for every element in the mesh are collected the following system of equations is produced:

$$\delta\tilde{\boldsymbol{\sigma}}^{(i)} = \boldsymbol{B}\boldsymbol{u}^{*(i)} \tag{1}$$

where B is the global strain-displacement matrix. It is important to stress that every parameter will come with its own sensitivity maps and accordingly will yield a different set of virtual fields.

Impact of DIC filtering

The regularization properties (subset size, step, shape function, strain method etc.) of full-field measurements as DIC might have a substantial impact on the involved sensitivity maps and accordingly on the performance of the automatically-defined virtual fields. In order to study the impact of DIC filtering effects an identical methodology is adopted as outlined in [2] based on synthetic image deformation. Hereby, a virtual set of experimental images is created with benchmark input material parameters. The numerical deformed speckle images are created via MatchID's finite element deformation module [3], with image deformation expressed in the reference configuration based on the shape functions of the corresponding nodes and end up in integer pixel locations in the deformed image. This not only avoids extra interpolation steps but also guarantees that one naturally arrives at a Lagrangian prescription of the image deformation process [4]. These are then analysed by a DIC platform [3] with a quantified set of user variables. Finally, seamlessly feeding the resulting strain fields into the VFM module[3] allows material parameter extraction and validation with the known reference parameters.

Case study and Conclusions

The method was tested using simulated Abaqus data from a uniaxial tensile test on a double-notched specimen as depicted in [1] and a specimen with a set of circular stress concentrations as in Fig. 1. Gaussian noise with a standard deviation of 0.7% was artificially added to the simulated strain data to simulate typical noise levels during an actual experiment. It is important to stress that in contrast to Ref. [1], a large strain formulation has been adopted with corresponding stress fields expressed in the first Piola-Kirchoff convention allowing the VFM to apply boundary conditions in the reference configuration.

The applied DIC settings and retrieved strain resolution are summarized in Table 1. Additionally, MatchID's missing data compensation technique has been imposed in order to retrieve data up to the edges of the specimen, hereby relying on the subset shape functions.

Technique used	2D DIC
Pre-Filtering	Gaussian – Kernel 5
Subset	21
Step	3
Correlation criterion	ZNSSD
Shape function	quadratic
Interpolation function	Bicubic splines
Total number of images	50
Strain	
Smoothing method	Polynomial – bilinear
Strain window/ VSG	5 / 43 pixels
Resolution	157 µm/m

Table 1: Adopted DIC settings

Table 2 contains the results of a basic isotropic Von Mises plasticity model adopting linear hardening, and a hyperelastic first-order Mooney-Rivlin model. The conference presentation will encompass a more broad variety of non-linear model results. It can be depicted from both tables that the sensitivity-based virtual fields outperform the uniform defined ones, reproducing the input parameters with high accuracy despite the involved DIC filtering effects.

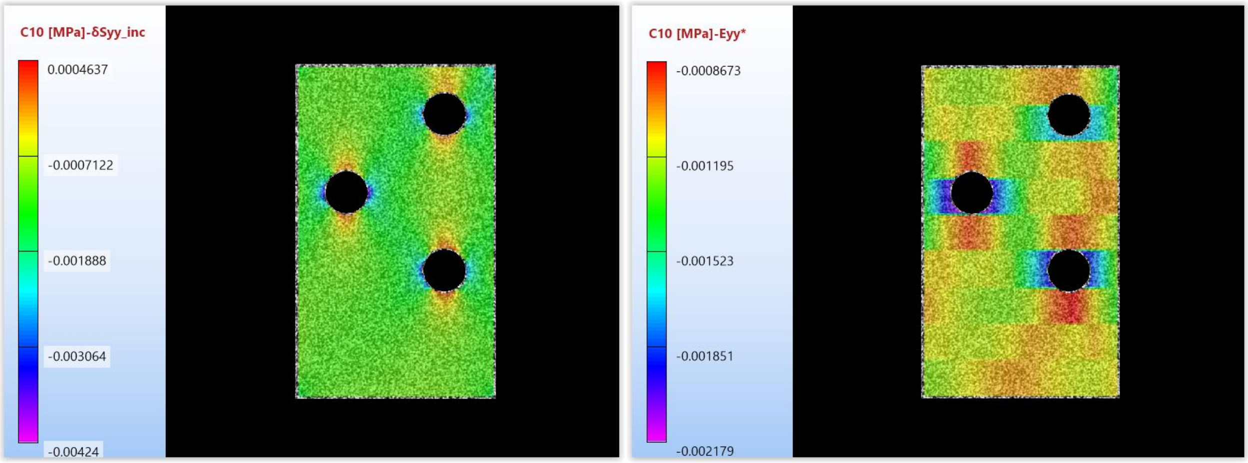

Figure 1: Incremental stress sensitivity map for C10 at 0.5 N (left panel) and corresponding longitudinal virtual strain field adopting a 9x9 virtual mesh.

	Plasticity Linear Hardening		Hyperelastic Mooney-Rivlin	
	σ_0/σ_0^{ref}	H/H^{ref}	C_{10}/C_{10}^{ref}	C_{01}/C_{01}^{ref}
Uniform	0.94	1.16	1.038	1.1
Incremental Sensitivity	1.006	0.987	0.998	1.08

Table 2: Identified parameter results

References

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