

Improving material parameter identification using spline FFD-based optimization of specimen shape.

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Abstract — Given the today genuine digital revolution experienced in experimental mechanics, it appears possible to identify numerous mechanical parameters using a limited number of tests provided that the latter are finely optimized. In this context, we design a full numerical methodology for the shape optimization of the specimen with respect to identification ability. It is based on an adequate modeling of the optimization problem and on an advanced numerical resolution procedure using splines and the Free-Form Deformation concept. It results in a non-invasive CAD-based shape optimization procedure that allows to decrease the uncertainty on the identified constitutive parameters by a factor of 30.

Keywords — Data Assimilation, Parameter identification, Digital Image Correlation, Shape optimization, Sensitivity analysis, CAD-based optimization.

Introduction Characterizing the mechanical behavior of materials is crucial to correctly model structures. It implies choosing an adequate constitutive law and determining the associated constitutive parameters. In the standard industrial practice, identifying several constitutive parameters requires designing several different experiments, and identifying a single parameter requires carrying out up to dozens of experiments, which makes the overall process very costly and time consuming. However, with the current advent of imaging techniques, the experimental mechanics area is experiencing a genuine digital revolution which allows for providing massive amount of data, in particular full-field displacement measurements with the Digital Image Correlation (DIC) technique. This opens the door for identifying numerous mechanical parameters using more complex mechanical tests in a limited number.

The challenge therefore consists in developing a numerical methodology to design innovative experimental tests that allow to identify, at best, multiple mechanical properties. At this time, it seems that very little work has been achieved in this direction. We may essentially note the contributions of [1] and [2] that propose to optimize some (very limited) shape parameters of the specimen (holes diameter or position), so as to identify several constitutive parameters at once with low uncertainty using the Finite Element Model Updating (FEMU) method. Alternatively, Chamoin *et al.* [3] used a topology optimization to maximize the sensitivity with respect to a single constitutive parameter, so that the resulting optimization problem can be solved without any *a priori* knowledge on the specimen shape. Besides extending the strategy to several constitutive parameters to identify leads to a more complex functional, the drawback is that the optimization problem may not be constrained enough and therefore may lead to strange configurations with respect to the involved mechanics.

Methods Our goal is to improve the shape of an existing specimen, therefore we will only consider shape optimization here (and not topology optimization). To tackle this issue, we propose to use a smaller yet rich and regular design space, based on splines and on the Free-Form Deformation concept. More precisely, our method consists in embedding parts (or features) of the geometry to optimize, described in our case by a FE mesh, into a spline morphing box of which control points drive the deformation of the geometry. From a conceptual point of view, the developed approach is very close to the one that we

recently introduced for general measurements in DIC [4]. It results in a CAD-based shape optimization that is of very low invasiveness with respect to a standard FE code (same idea as in [5]).

Regarding the modeling of the optimization problem, the key point is to study the spectral properties of the identified parameters covariance operator due to measurement noise in order to maximize the sensitivity of the measured displacement fields to those parameters [1]. In addition, we equip the optimization problem with well chosen constraints to meet experimental requirements. In particular, we add a normalization of the cost function to take into account the position of the camera while the area of the specimen spreads out, and we add maximal stress and minimal Jacobian constraints to separate the effect of loading and ensure a physically sound specimen geometry, respectively.

Results The method is applied, in particular, to optimize the shape of holes in a traction beam for the identification of all orthotropic linear elastic constitutive parameters (see Fig. 1). A 1D B-spline morphing box is created to drive the movement of the FE nodes along the hole boundaries. Starting with the geometry of Fig. 1(top), the optimization leads to the geometry shown in Fig. 1(bottom). We will see that it is possible to improve the cost function value by a factor 30 while maintaining an equivalent maximal stress value. That means the uncertainty on the worst identified parameter is lowered by an order of magnitude and that the same experimental set-up than with the initial specimen can be used.

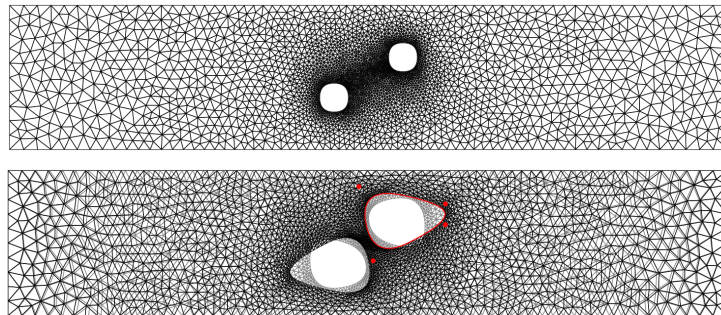


Figure 1: Top: Initial geometry with B-spline description of the holes geometry. Bottom: Improved geometry (in black) compared to the initial geometry (in grey), and 1D FFD morphing box and its control points position at the end (in red)

Discussion and Conclusion Making use of a fine modeling of the higher-level optimization problem of maximizing the sensitivity of constitutive parameters, and of advanced numerical tools coming from the shape optimization community in computational mechanics, we have been able to design a full numerical methodology that deeply improves the specimen shape for mechanical characterization. The extension of such a technology to non-linear constitutive parameters, with expected difficulties both in terms of implementation and numerical complexity, may represent a very interesting avenue in the near future.

References

- [1] M.B.R. Bertin, F. Hild, and S. Roux. Optimization of a cruciform specimen geometry for the identification of constitutive parameters based upon full-field measurements. *Strain*, 52(4):307-323, 2016.
- [2] N. Feld, H. Laeuffer, and S. Roux. Mesure de champs hétérogènes pour l’identification du comportement de matériaux composites stratifiés. *Comptes-Rendus des JNC*, 9, 2015.
- [3] L. Chamoin, C. Jailin, M. Diaz, and L. Quesada. Coupling between topology optimization and digital image correlation for the design of specimen dedicated to selected material parameters identification. *International Journal of Solids and Structures*, 193:270-286, 2020.
- [4] M. Chapelier, R. Bouclier, and J.-C. Passieux. Free-Form Deformation Digital Image Correlation (FFD-DIC): A non-invasive spline regularization for arbitrary finite element measurements. *Computer Methods in Applied Mechanics and Engineering*, 384, 113992, 2021.
- [5] G. Colantonio, M. Chapelier, R. Bouclier, J.-C. Passieux, E. Marenic. Noninvasive multilevel geometric regularization of mesh-based three-dimensional shape measurement. *IJNME*, 121:1877-1897, 2020.