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Non-invasive regularization of 3D shape measurement using splines

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Abstract —

Finite Element Stereo Digital Image Correlation allows measuring 3D displacement fields on 3D surfaces, using the FE discretization space. Shape measurement is necessary prior to any experimentation, yet an analysis-suitable FE mesh leads to an ill-posed problem. To circumvent this issue, we propose to project the FE space onto a smoother space and choose spline functions. We use an explicit link between both spaces to develop a non-invasive method. We show that projection on a spline functions space increases regularity and that spline properties offer other interesting possibilities like a multilevel approach.

Keywords — Stereo-Correlation, Multilevel Design, Free-Form Deformation

Introduction Stereo Digital Image Correlation (SDIC) is a convenient way of measuring 3D displacement fields on 3D surfaces, using several cameras. Among other choices, Finite Element based (FE-based) methods seem appropriate because they can be coupled with numerical models. It allows measured data and simulated results to be defined at the nodes of the same mesh, thus simplifying their comparison.

Prior to any experimentation, a calibration phase must be carried out in order to determine the parameters of the cameras and the actual shape of the specimen. Since the FE mesh is the same for measurements and simulations, it needs to be analysis-suitable, that is to say fine enough to correctly represent the mechanical problem solution. However, it leads to an ill-posed problem when identifying the shape, which results in unrealistic geometries. This issue is generally addressed by adding a smoothing term to the objective function to minimize, or performing a post-treatment phase, usually using smoothing filters.

Methods Our approach consists in projecting the problem onto a smaller, smoother discretization space. To do so, we choose spline functions, because of their high regularity [1]. These functions are commonly used to describe geometries in Computer-Aided Design. A non-invasive link is then created which enables a standard FE software to be used [3].

One of splines interesting properties is their ability to be refined without any modifications in the geometry. We take advantage of this property and propose a multilevel approach [2]. As shown in Figure 1, measurements are first carried out on a coarse CAD geometry and then used as an initialization for finer CAD geometries. The process is repeated to get the desired precision.

Specimen shape measurement is achieved together with camera calibration using a fixed point algorithm. Assuming the intrinsic parameters of the cameras to be known, only six extrinsic parameters have to be found for each camera, corresponding to their position and orientation. For two cameras, the objective function to minimize thus writes:

$$\underline{S}^*, \underline{p}^* = \underset{\underline{S}\in L_2(\Omega_S),\underline{p}\in(\mathbb{R}^6)^2}{\operatorname{argmax}} \frac{1}{2}\int_{\Omega_S}\left[\mathcal{I}_0(\underline{P}_0(\underline{X}+\underline{S}(\underline{X}),\underline{p}_0)) - \mathcal{I}_1(\underline{P}_1(\underline{X}+\underline{S}(\underline{X}),\underline{p}_1))\right]^2 d\underline{X} \tag{1}$$

with $\underline{S}$ the shape correction, $\mathcal{I}_i(\underline{x})$ the i^{th} image ($\underline{x}$ in pixels) and $\underline{P}_i(\underline{X},\underline{p}_i)$ the projection going from a

point in the world space $\underline{X}$ and camera parameters $\underline{p}_i$ to a point in the pixel space.

A Gauss-Newton minimization is then performed. The shape measurement and the extrinsic parameters are obtained by iteratively solving such equations:

$$\underline{\underline{H}}^k_{FE}\,\underline{dp}^k = \underline{b}^k_{FE}. \tag{2}$$

Results We implemented an explicit link between the FE operators and the CAD degrees of freedom (dof) so that the CAD dof drive the shape measurement. It is possible to choose the research space for admissible geometries by refining spline functions as desired. A first approach was based on the CAD geometry of the structure and led to very smooth design. The results of this approach with multilevel design can be seen on Figure 1. This multilevel approach was found to be more effective than standard methods. Another approach using a generalization of the link between FE dof and CAD dof was also developped to increase the geometry and mesh possibilities. The latter is based on the concept of Free-Form Deformation (FFD) applied, e.g., in aerostructural optimization [4]. The proposed method does not need the addition of any regularization term, nor any post-treatment.

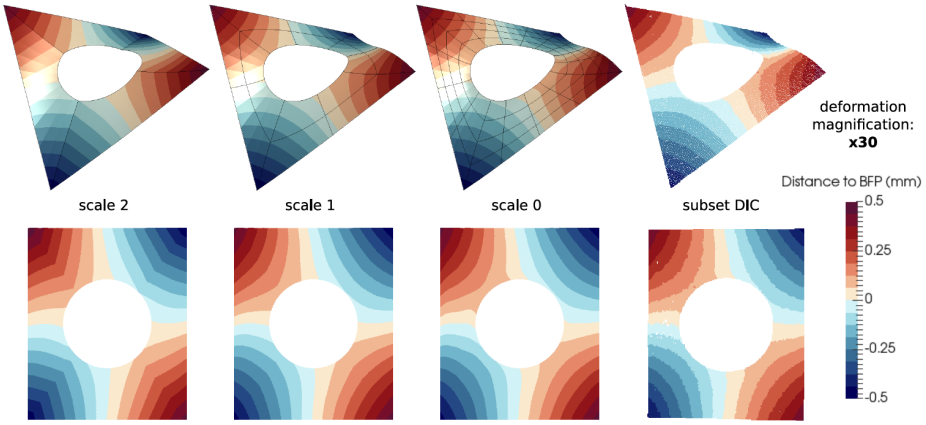

Figure 1: Twisted specimen and proposed regularization. The visible mesh is the CAD mesh, and analysis is performed on a finer FE mesh.

Discussion and Conclusion Using spline functions subspace has multiple advantages. Their high smoothness makes the problem more regular. It worths noting that the FE mesh and the FE-CAD link have to be created only once even though the CAD geometry is changing at each iteration. Exact refinement is an important feature of spline functions that allows a multilevel approach, which gives promising results. Finally, our method allows using a standard FE-SDIC software in a non-invasive way.

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