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## ON THE NON-INVASIVE ADAPTIVE SPLINE REGULARIZATION OF FINITE ELEMENT DIGITAL IMAGE CORRELATION

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### ABSTRACT

Finite-Element Digital Image Correlation (FE-DIC) now appears highly relevant in the experimental mechanics community thanks to its direct bridge with simulation. However, using the fine FE mesh generated for accurate simulation inevitably requires the proper regularization of the inverse DIC problem. Here, Truncated Hierarchical B-Splines (THBS) are considered in a Free-Form-Deformation DIC approach to regularize FE-DIC in a strong, non-invasive, and adaptive manner. The idea is to embed the fine FE mesh in a THBS box whose unstructured refinement is automatically performed during the process to arrive at an optimal number of Degrees Of Freedom (DOF) for the solution. The FE DOF are related to the THBS DOF so that we end up with a regularized but conventional FE measured field which can be computed from a standard FE-DIC code. The method is also extended to cover stereo-DIC applications.

**Keywords:** digital image correlation, stereo-correlation, hierarchical B-splines, adaptive refinement, free-form deformation

### INTRODUCTION

Digital Image Correlation (DIC) has become one of the most commonly used techniques to obtain full-field measurements on structures. More than a 2D technique, it also efficiently extends in 3D with the stereo-DIC that makes use of several cameras to access the three components of the displacement at the non-planar surface of a specimen. Among multiple variants, the Finite-Element (FE) DIC [1,2] has widely spread in view of performing mechanical identification [3]. Indeed, it offers the opportunity to measure the displacement field with the *fine* FE mesh used for accurate mechanical simulation. However, the drawback is that the measured field generally contains too many Degrees Of Freedom (DOF) compared to the data provided by the experiment, which makes the DIC inverse problem severely ill-posed.

It is therefore requested to regularize FE-DIC, which can mainly be done either strongly by modifying the size of the approximation space, or weakly by adding a Tikhonov-like penalization term consistent with the mechanical behavior to be captured. For the sake of generality here in terms of observations, we opt for the first alternative. We actually resort to spline functions. Given their higher regularity and thereby their limited number of DOF to adequately describe the displacement field, the latter have proved to ameliorate the conditioning of the DIC (including stereo-DIC) problem [1]. Taking the concept even further, a spline adaptive refinement algorithm has been proposed for 2D-DIC in [4], which allows to automatically adjust the spline functions to arrive at an optimal regularization. Nevertheless, these spline technologies require to implement spline functions in the DIC framework and, more importantly, they lead to an experimental displacement field that is not directly comparable with the output provided by most of today's simulation tools.

In this context, the purpose of this contribution is to extend the strategy in [4] to make it work with the input *fine* FE mesh coming from simulation. Moreover, we seek to enlarge the scope

of the method by applying it for stereo-DIC in addition to standard 2D-DIC. To do so, our idea is to make use of the recent Free-Form Deformation (FFD) FE-DIC [5], which consists in embedding the input FE mesh in a spline box and to relate the nodal FE DOF of the measured field to a more regular field described by the box (see Fig. 1(a)). Here Truncated Hierarchical B-Splines (THBS) [6] are considered for the box and a self-adaptive refinement algorithm based on the greylevel residuals is implemented to arrive at an optimal number of DOF for the solution. The approach is non-invasive in the sense that it results in a regularized but conventional FE measured field which can be computed from a standard FE-DIC code.

## RESULTS AND CONCLUSIONS

Let us consider as a preliminary test case an initial planar plate presenting a local defect that can be described as a sinusoid. As expected, the refinement algorithm leads to finer elements around the sinusoid to properly capture the shape defect, while larger elements are used elsewhere to minimize the total number of spline functions (see Fig. 1(b)). During the talk, different test cases covering 2D-DIC and stereo-DIC will be presented and finely investigated.

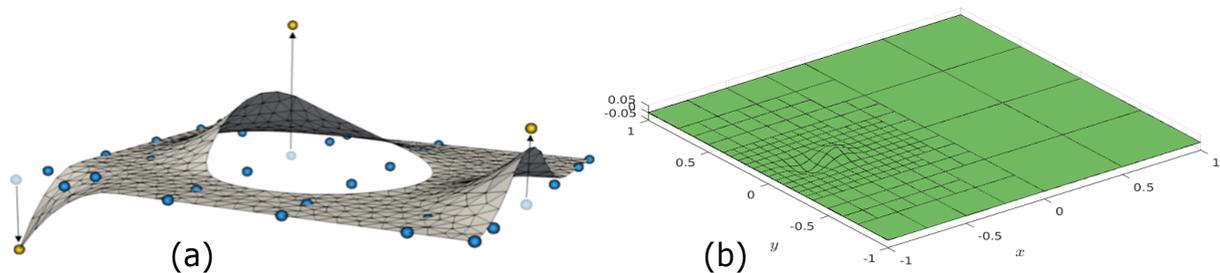


Fig. 1 – (a) Deformation of a FE mesh using FFD. The blue dots are the control points of the spline box. Moving these points (yellow dots) results in a displacement of the FE mesh nodes (image taken from [5]). (b) Final THBS box allowing the proper representation of a local defect while minimizing the total number of spline functions.

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