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A new numerical scheme for the measurement of strain fields in cellular microstructures.

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Abstract — Full field measurements provided by digital volume correlation (DVC) would undoubtedly contribute to a better understanding of the mechanical behaviour of cellular materials. Nevertheless, when dealing with micro-structures that do not exhibit sufficient micro gray level gradients, traditional digital image correlation (DIC) algorithms lead to a rough spatial resolution that does not allow capturing local strains. In this critical situation, one effective method to increase spatial resolution while mastering measurement uncertainties is the use of mechanical regularization of the underlying optimization problem.

Keywords — Digital Volume Correlation, elastic registration, B-splines, fictitious domain methods, image based models, cellular materials.

Introduction With the recent advances in imaging techniques such as Computed Micro-Tomography (μ -CT), it is possible to acquire volumetric images of the micro-structure of complex heterogeneous materials in a non-invasive way. In the following, the focus is on full-field measurement in cellular materials such as foams. DVC in complex micro-structures presents multiple changes and challenges when compared to 2D DIC. For instance, in most two-dimensional cases, a speckle pattern can be deposited onto the sample in order to introduce sufficient gray-level gradients in the images. Conversely, for DVC, the only information available is the intrinsic gray-level distribution related to the microstructure. That is why it seems that conventional DVC algorithms can only be applied when materials exhibit a natural speckle pattern (for instance graphite nodules [1]). Our objective is to develop a correlation algorithm that can capture local deformations at the micro-structural scale using only the natural texture of the studied material. To do so, we suggest constructing an automated digital image-based mechanical model and using it to regularize the ill-posed problem of DIC.

Methods Given two images of a cellular specimen captured during a mechanical test, we are considering regularizing the DIC problem using a penalization term based on the equilibrium gap [2]:

$$\arg \min_{\mathbf{u}} \frac{1}{2} R(\mathbf{u}) + \frac{\lambda}{2} \|\mathbf{K}\mathbf{u}\|_2^2 \quad (1)$$

where R is the discrete sum of squared differences between the initial and the advected images, \mathbf{u} is the displacement vector at the control points of a cubic structured B-spline grid defined over the region of interest and \mathbf{K} is an elastic rigidity operator that simulates the mechanical behavior of the texture being observed. Our contribution concerns the automated construction of a fairly priced image-based model that allows to obtain \mathbf{K} . To do so, we use a high order fictitious domain method using a level-set representation of the materials boundary [3, 4]. We mean by fairly priced the fact that our model's parameters (mesh size and degree of approximation) are set such that the error made on the mechanical solution is insignificant compared to the geometric errors related to the image-based geometry approximation. In contrary to boundary-fitted meshing techniques, the degrees of freedom of the fictitious domain method are defined over all the specimen's region (including the empty black region in Fig. 1a). We emphasize that \mathbf{K} is defined only at the degrees of freedoms on which the elastic forces are known.

Results In order to validate our method, we consider measuring the strain field on a planar specimen representing a two-dimensional cellular material (see Fig. 1a). Fig. 1b shows that the suggested mechanical regularization allows to measure accurate strain fields compared to traditional low order interpolation schemes and this using only the natural texture of the specimen.

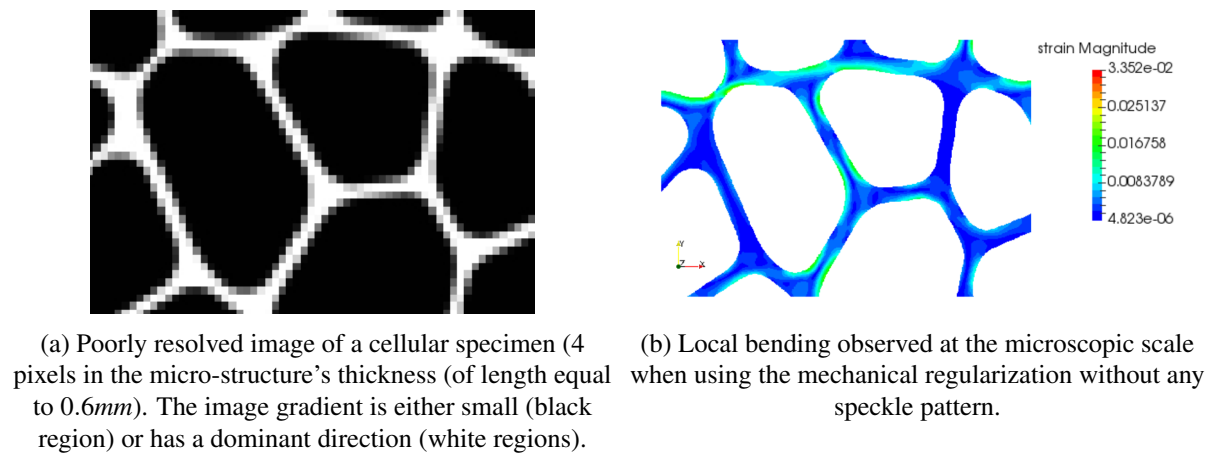


Figure 1: Strain measurement at the microscopic scale in a cellular specimen.

Discussion and Conclusion High order basis functions such as B-splines, allow to capture non-rigid and smooth displacements in the contrary of low order registration techniques. This method was validated in two dimensions for synthetic images. Its generalization to real foam specimens will be done in the future and we assume that the three-dimensional generalization is only related to the computational complexity and efficiency. However, multiple challenges are still open concerning the elaboration of an *in-situ* mechanical test using micro-tomography. In fact, in order to acquire sufficiently resolved images, we need to consider small volume samples. This constraint obliges us to resort to adapted mechanical testing machines so as not to disturb the tomography acquisition system [5].

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