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Dynamic in-situ 4D measurement in a lab tomograph

Clément Jailin *[1], Ante Buljac[1], Amine Bouterf[1], Martin Poncelet[1], and Stéphane Roux[1]

[1]LMT (ENS Paris-Saclay/CNRS/Univ. Paris-Saclay), 61 avenue du Président Wilson, F-94235 Cachan (FRANCE)

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Summary: 4D motion during a scan acquisition in a lab-tomograph is measured using a recently developed Projection-based Digital Volume Correlation (P-DVC) method in no more than 1.3 s acquisition time per state. The 4D procedure exploits an initial full reconstruction of the sample obtained by classical means. Following 100 motion steps, the full space-time displacement field is measured based on one radiograph.

1. INTRODUCTION

The development of material tests coupled with tomographic images has been studied in the recent years. After *ex situ* testing where the materials are deformed outside of the tomograph, the recent evolution of CT makes in-situ tests possible. Nevertheless, except for few recent works performed in synchrotron facilities [1], the major limitation of CT imaging especially in lab-tomograph is the acquisition time (around one hour).

One possible procedure to circumvent this difficulty is the Projection-based DVC (P-DVC) [2]. Instead of working with full 3D images for every loading step, it consists in operating directly on radiographs (i.e., projection of the deformed volume). A very small number of radiographs turns out to be sufficient to measure a displacement after a first complete 3D image of the reference state has been (classically) reconstructed. In [3], it has been shown that the measurement of the 3D displacement field of a specimen of cast iron with a fatigue crack was obtained from no more than two radiographs (instead of 600).

In order to reduce the number of unknowns, the kinematic is not expressed as independent moving voxels but on a reduced basis composed of few mechanically admissible elementary fields. They are built from sensitivity fields that can be boundary conditions, crack position, material parameters... This coupling between model and experiment permits to consider jointly the force and displacement measurement. This strong regularization is based on mechanical assumptions that are to be validated resorting to the residual fields (i.e. the remaining difference between the radiographs and the deformed projected volume at convergence).

In the proposed 4D approach, we aim to identify the 3D displacement field from a single radiograph at each motion step. Because of the projection operator, a part of the information (e.g. displacement in the direction of the rays) is lost. Hence, to be sensitive to all dofs, a temporal regularization has to be added and the acquired angles distributed all around the sample.

2. EXPERIMENTAL-NUMERICAL METHOD

The application is a tensile test on a cast iron sample. At each mechanical step, from 0 to 700N, the load is stopped and during the acquisition, the sample moves. This motion that may be due to a wrong rotation axis, relaxation, thermal effects or a displacement of the plate blurs the 3D reconstruction. It is proposed to study this motion that can not be measured by standard means and correct the radiographs. For that purpose, a fast scan composed of 1000 radiographs acquired every 1.3 s is analyzed projection by projection thanks to its own reconstruction that is the reference volume of the P-DVC procedure.

The sample was scanned at the LMT lab-tomograph inside of an *in situ* testing machine [4] with a load measurement. The voxel size at full resolution was set to 2.8 μm. The reconstruction (FBP) and projection operators are issued from the ASTRA toolbox [5].

*e-mail: clement.jailin@lmt.ens-cachan.fr

The spatial regularization is performed with a reduced basis composed of the rigid body motions of the sample and a tensile/compressive displacement field. Finally, the identified motion is described as a combination of few displacement modes weighted by time amplitudes that are identified successively.

3. RESULTS

The results are shown for the analysis of a set of 70 radiographs regularly spaced in time (and angles). The identified displacement field is essentially composed of 4 modes associated to time amplitudes. The 3 first extracted modes are rigid body motions. The first mode displacement field and associated amplitude is shown in figure 1. This field is a 10 μm amplitude vertical displacement and a large rotation. Then a compressive mode can be identified.

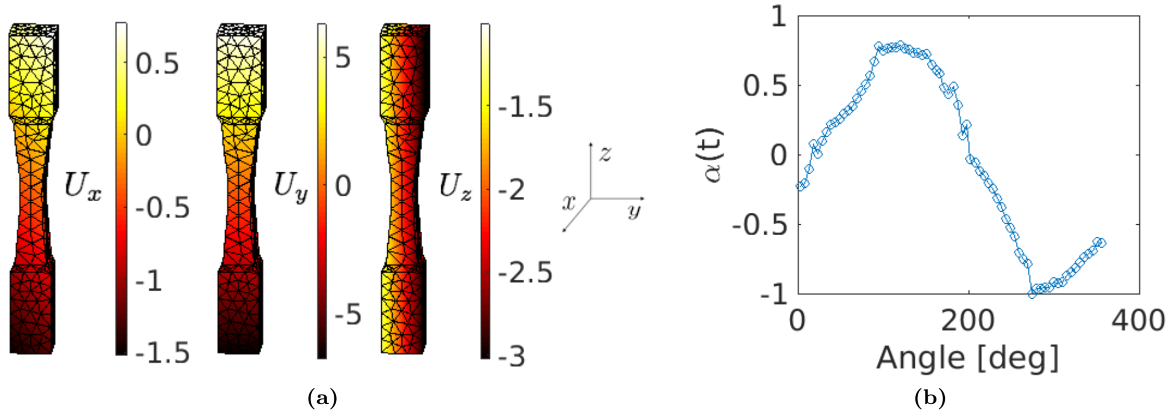

Figure 1: 3D displacement field for the first rigid body mode (a) in the x,y and z direction expressed in voxels (1 vox→2.8 μm for a 900 vox length specimen) associated to the temporal amplitude $\alpha(t)$ (b). This displacement corresponds to a vertical translation and a rotation along the x direction. It can be noted that $\alpha(t)$ that results from independent computations for each step is not much noisy hence is an accurate amplitude of the identified displacement

The proposed integrated P-DVC method aims at projecting the residual image field due to the motion of the sample (the difference between the projected reference volume, corrected by the displacement field and the radiographs of the actually deformed state) onto the displacement sensitivity basis. Hence the evolution of residual fields is a good estimator of the quality of the procedure.

The residual fields at the end of the identification are very low compared to the initial ones. Visually these fields are composed of high frequency noise. The previous alternating positive and negative patterns (signature of a displacement visible figure (a)) have been erased, confirming that the kinematic part of the residual has been well captured.

Finally the displacement field are used to correct the radiographs and reconstruct a volume of better quality (with sharper interfaces) and without motion artifacts on the reprojections.

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