TOMOWARP2: MEASURING 3D DIPLACEMENT FIELDS THROUGH DIGITAL VOLUME CORRELATION

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Summary: TomoWarp2 is a python based code that allows the measurements of 3D displacement and strain fields from repeated scans of an object subjected to deformation

1. INTRODUCTION

In experimental mechanics strains are traditionally calculated from measurements of displacement made at the boundaries of a tested sample, which implies that a homogeneous behaviour of the material has to be assumed. Digital Image Correlation, and in particular its 3D volumetric version Digital Volume Correlation (DVC), has proven to be a powerful tool that can provide full-field measurement of kinematics and strains within objects during their deformation. This is essential in experimental tests of a number of materials, such as geomaterials, porous materials and biomaterials, that are heterogeneous by nature and/or deform in a non homogeneous manner. Therefore, this method has been used increasingly over the last decades in a range of experimental mechanics applications. The principle of DIC is to assess the displacements fields, and thus strains fields (if required) by comparison of two images acquired at different stages of deformation. The first image is generally referred to as the reference image and the second, acquired after an increment of deformation, as the deformed image. These two images can be acquired by any kind techniques and can be 2D or 3D. In the case of tomographic scans, DVC provides a 3D field of three components of displacement vector; applicable to analysis of 3D deformation including internal deformation.

2. METHODOLOGY

TomoWarp2 is a python-based code, developed in cooperation between the University of Lund and the Laboratoire 3SR in Grenoble, and is based on the earlier TomoWarp code [1]. The implemented method belongs to the local variant of image correlation techniques, in which the first step consists in defining a grid of analysis points over the reference image; then, a group of pixels surrounding each node of this grid, commonly called a subset, is determined. For each node, the most similar subset in the deformed image is identified based on some statistical measure of correlation (in this contest the normalised correlation coefficient). This operation, which is performed only within a reduced area of the deformed image (the search window), provides the discrete displacement (integer number of pixels). A more realistic displacement can then be found by performing a sub-pixel refinement that can be achieved using a number of different procedures.

TomoWarp2 offers two different implementations

- "CC-interpolation" – involves the interpolation of a set of correlation coefficients corresponding to integer displacements by a mathematical function. The maximum of this function gives the sub-pixel resolution displacement. For a more detailed description of the method see [2] for example.
- "image interpolation" – numerically displaces the subset of the deformed image until it matches the reference one. The order of the image interpolation is an input. The implementation of this method is

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much more computationally expensive than the CC-interpolation, but allows rotational degrees of freedom to be taking into account easily.

It is common to complete DIC analysis with calculation of the strains, which is based on standard continuum mechanics approaches starting from the measured displacements. The code provides the choice between different frameworks for the strain calculation, such as small and large strain, and the use of cubic or tetrahedral elements.

3. APPLICATIONS

TomoWarp2 has been used principally to study geomaterials' mechanical behaviour, *e.g.*, [3, 4, 5], but also to tackle questions outside the field of geomechanics, such has the internal deformation of batteries during charging/discharging cycles [6, 7] or the failure mechanisms of bones and bones/implant interface [8].

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