DVC in dynamic CT reconstruction for material characterization

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Summary: Non-rigid motion of objects studied by tomography is often both a valuable source of information and a nuisance in terms of reconstruction. This work aims for improved DVC analysis in close connection with the CT reconstruction of dynamic processes. This allows for a better characterization of materials with internal processes that happen in time scales of several seconds.

1. INTRODUCTION

Computed Tomography (CT) is increasingly used as a 3D imaging technique of dynamic internal phenomena [1]. Lab-based experiments are becoming an important option compared to synchrotron facilities, since the scanner can be rotated around the sample in dedicated setups [2]. This allows for easier incorporation of peripheral tools to facilitate dynamic processes. However, the much smaller flux bounds the possible time resolution.

An important new mode of the dynamic processes is the non-rigid motion of the studied objects. While this introduces difficulties in reconstruction, it yields some very important information on the processes too. Most severely, the assumption of a static volume during the scan is violated. This results in motion blurring when the deformations are too large compared to the rotation time. A trade-off is made with the acquisition time of each projection, which in turn leads to lower statistics. When the reconstruction quality is reasonable, the time variation of the derived deformations give insight into the internal dynamics of the scanned object.

In previous work by De Schryver et al. [3], Digital Volume Correlation (DVC) was successfully implemented in an iterative reconstruction strategy to compensate for motion artefacts. Various samples have been investigated, ranging from dough leavening to pressure tests on metallic foam structures. The B-spline registration with adaptive stochastic gradient descent optimisation, which is available in the *SimpleElastix* module [4], emerged as an accurate and robust technique to estimate deformation fields, across a wide range of feature scales.

Now the goal is to further analyse and exploit the dynamic information in the sequence of time steps for a variety of materials. Extensions to the current DVC methods are implemented and evaluated.

2. METHODS

Coupled DVC DVC is usually performed to match two tomographic reconstructions. A similarity metric $\mathcal{S}$ between the reference and target volume is optimized by adding a local displacement field u. When a time series of reconstructions ($\mu_\tau,\ \tau = 0, 1, \ldots, t$) needs to be matched, the DVC algorithm can be extended in a number of ways. One possibility is to use a global similarity metric with an added check so the cumulation of incremental displacements u_τ remains consistent over larger time scales. ν is a time-dependent scaling factor.

$$\mathcal{S}_g = \sum_{\tau=1}^{t} \left[\mathcal{S}(u_\tau; \mu_{\tau-1}, \mu_\tau) + \nu(\tau)\mathcal{S}\left(\sum_{\tau'=1}^{\tau} u'_\tau; \mu_0, \mu_\tau \right) \right] \tag{1}$$

The method is checked by performing a series of uncoupled DVCs and the coupled DVC for a 4D CT scan of metal foam under pressure. Then the consistency at the last time instance is compared.

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Motion corrected SART To correct for motion artefacts, the displacement fields derived from the DVC algorithm are incorporated in the iterative reconstruction method. The sample can be assumed stationary if the deformations due to dynamic processes are compensated correctly. The back-projection step is carried out to a representative time stamp τ_R, while the projection is simulated on the estimated deformed state at the time τ_r when the real projection was acquired. This is achieved by redefining the sampling coordinates according to the interpolated displacement field. The results are assessed both visually and by mapping the reconstruction on the reference volume.

Material characterization DVC yields a displacement field that links the volume at each time step to the original state. From this displacement field, a strain tensor is derived. In accordance with the actual CT volume, which shows the distribution of materials in the internal structure, stress fields can be modelled. The location and time dependence offer valuable information for material characterisation and design. In figure 1 an actual CT visualisation experiment on the compression of the aluminium foam mentioned above is displayed [5]. The von Mises stress is deduced by adopting a linear elastic and isotropic material model. It shows that stresses tend to build up at the interface with the compression plates for this sample.

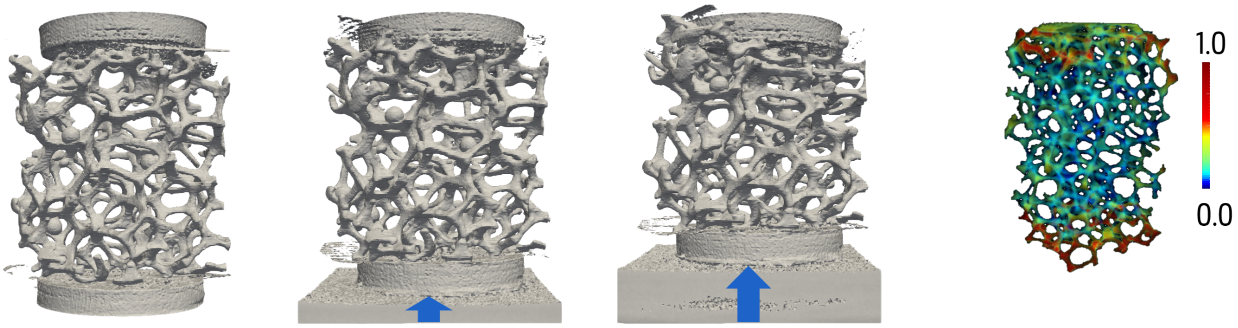

Figure 1: An aluminium foam is compressed with continuously increasing load while performing multiple CT rotations. DVC algorithms deduce the local displacements, which are useful for material characterization. On the right image the von Mises stress is depicted, normalized to the maximal value.

A coupled DVC method to improve consistency in the displacement fields is proposed and evaluated on CT data. Through the motion compensated reconstruction, strain analyses can be performed on dynamic samples that currently deform too fast to achieve an image without motion artefacts at the needed resolution.

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