DYNAMIC CT RECONSTRUCTION USING PIECEWISE LINEAR FITTING

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Summary: A dynamic multi-rotation CT-scan is reconstructed by "statically" reconstructing each rotation of the scan which results in a time series of 3D volumes. Each voxel has a number of data points representing the reconstructed attenuation coefficient in function of time. In this work a piecewise linear function is fitted to these data points. This allows to obtain information from less than one rotation for each 3D volume, thus increasing the temporal resolution.

1. INTRODUCTION

Dynamic or 4D computed tomography (4D CT) addresses the CT-scanning of samples that change or move during the scan. In this case it is difficult to reconstruct the correct volume, because a reconstruction assumes a static sample and uses many projections which are taken during a certain time period (depending on the setup). During this period, the sample has changed and violates the assumption of a static volume. In addition, dynamic scans are generally taken with fast rotations to allow for the visualization of highly dynamic processes. This results in a lot of noise in the images.
A lot of research has been done on how to best reconstruct 4D CT datasets. A technique often starts from a known 3D reconstruction method, adding prior knowledge or certain assumptions about the sample to the algorithm [1,2,3]. Any of the reconstructions made with these techniques could be used as a starting point for the piecewise linear fitting proposed here. The starting point should be a time series of 3D volumes. These can be noisy or have limited angle artefacts (as long as they don't all span the same angle). The goal of this work is to further improve the interpretation and analysis of the data.

2. GENERAL WORKFLOW

The first step is of course to prepare the sample (if necessary), perform the 4D CT scan and apply pre-processing correction to the projections (e.g. normalisation). The resulting projection images span a time t and a number of rotations. The reconstruction consists of the following steps:

1. Divide the series of projections in a number of 'time steps'. Each time step consists of a few projections, enough to obtain reasonable reconstruction quality. This depends on the sample, noise level and reconstruction method. Time steps may overlap. For example: when a full rotation consists of 360 projections, time step 1 might consist of projection 0 to 100, time step 2 projection 80 to 180, time step 3 projection 160 to 260, etc.
2. Reconstruct each time step with a method of your choice. For the results given in this work, a SART-reconstruction with an initial volume was used.
3. Plot the grey value of each voxel in function of its time. Fit a piecewise linear function to this and use the values of this fit as the new grey values.

The fitting is performed by performing a simple linear regression to parts of the grey-value dataset. The breakpoints (where one line stops and the next begins) are chosen at the points where these short lines differ the most before and after the breakpoint. Finally, linear regression is performed on the parts between breakpoints.

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3. RESULTS

Fluid flow through porous rock is an important topic in geology and can be visualised with dynamic CT [4,5]. The result of a scan of oil flow can be seen in figure 1. A reconstruction of a scan at higher quality taken before the fluid flow was initiated served as the initial volume for the reconstruction method.

It can be seen that the temporal fitting mainly works as a noise filter in the temporal direction. It also creates a cleaner image of the parts of the image that are changing – in this case the pores where the oil flows through (black in figure 1).

The fitting of a piecewise linear function doesn't only reduce noise. It can also take care of the limited angle artefacts in case each time step consisted of less than one rotation. Note that this only works if the full angular information is available in nearby time steps. It allows to make each time step smaller and thus have less effect of the time blurring within its range.

In figure 1 it can be seen that the fitting has a suboptimal choice of breakpoints. Further research on this topic is planned in the near future to optimize this.

References

[1] L. Brabant. Latest developments in the improvement and quantification of high resolution X-ray tomography data. Ph.D. dissertation, Dep. Phys. and Astr., Fac. Sciences, Ghent Univ., Ghent, Belgium, 2013.

[2] G. Van Eyndhoven, K. J. Batenburg & J. Sijbers. Region-based iterative reconstruction of structurally changing objects in CT. *IEEE Trans. Image Processing*, vol. 23(2), 909-919, 2014

[3] G. Chen, J. Tang & S. Leng. Prior image constrained compressed sensing (PICCS): a method to accurately reconstruct dynamic CT images from highly undersampled projection data sets. *Med Phys*, vol. 35(2), 660-663, 2008.

[4] T. Bultreys, M. A. Boone, M. N. Boone, T. De Schryver, B. Masschaele, L. Van Hoorebeke & V. Cnudde. Fast laboratory-based micro-computed tomography for pore-scale research: illustrative experiments and perspectives on the future. *Adv. Wat. Res.*, vol. 95, 341-351, 2016.

[5] M. Andrew, H. Menke, M.J. Blunt & B. Bijeljic. The imaging of dynamic multiphase fluid flow using synchrotron-based X-ray microtomography at reservoir conditions. *Transp Porous Med*, vol 110, 1-24, 2015.

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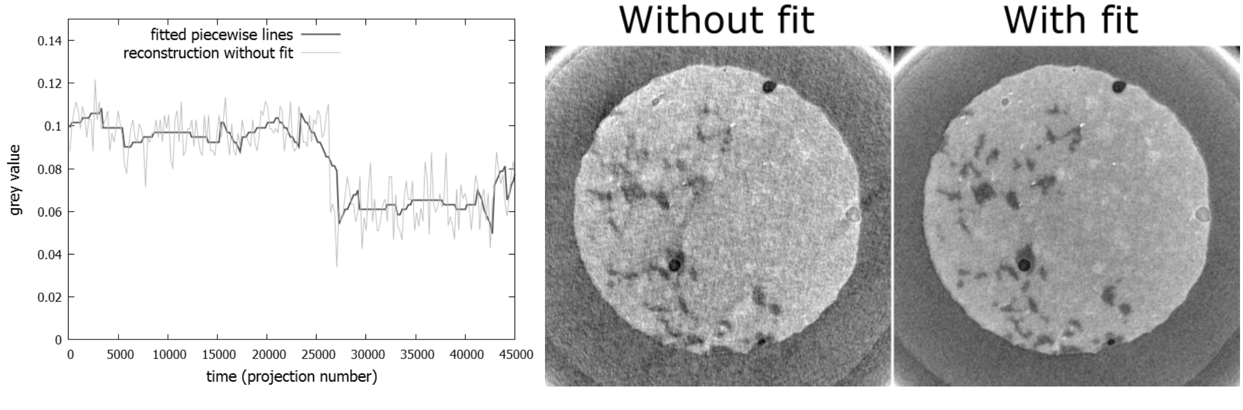

(a) (b)

Figure 1: (a) The temporal evolution of the grey value of one particular voxel, in the normal reconstruction and after a fitted piecewise linear function. (b) One slice of one time step, both with and without fit. The effect of the fit as a noise filter can be seen here.