True 3D-CT-reconstruction in comparison to the FDK-algorithm

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Introduction

As has already been shown with 2D-models DIRECTT[1,2] (Direct iterative reconstruction of computed tomography trajectories) exceeds the spatial resolution of the classical filtered back projection. In this work the DIRECTT algorithm is extended towards cone-beam projection including iterative 3D reconstruction. The improved speed is still overcompensated by the large amount of reconstruction space and therefore intensive usage of memory.

In comparison to the FDK[3] (Feldkamp-Davis-Kress) algorithm we achieved a better edge resolution in all dimensions using only 5 iterations. In particular artefacts far outside of the central plane are reduced significantly. Local smearing by focal spot size and/or real detector response can be integrated in order to increase the reconstruction quality.

These important improvements help using computed tomography in all kind of industrial applications.

Reconstructions obtained from simulated data as well as real measurements are discussed in detail.

Keywords: computed tomography, spatial resolution , reconstruction algorithm

State of the art

In the case of parallel beam projection the unfiltered back projection results in blurred images. For this reason a deconvolution with kernel 1/*r* is applied to the projections in each detector line with different well-known filters, followed by back-projection[4]. This method is well established and leads to reasonable results at tolerable computing time. Because of summation in the reconstruction matrix over the different directions of projection every element of the reconstruction is isotropic and can be described as a sphere. But these spheres cannot be considered as a gapless packed volume to represent a homogeneous density. For that reason and Nyquist's theorem[5] there is a inherent blurring of reconstruction of about 1.8 voxel which cannot be avoided.

In the case of cone beam projection usually the well-known FDK algorithm is used with some adaptions regarding filtering and back projection techniques.

Principles

In Fig.1 a series of equally sized voxels of the same phase and radius but different distance from the central detector plane is projected schematically. In case of cone beam projection the phase dependent and magnified projections (in analogy to fan beam projections) of voxels become elliptical traces on the detector (y–z plane of Fig. 1b). Their vertical half axes increases with the distance from the central plane. The respective voxel projections move both vertically and horizontally.

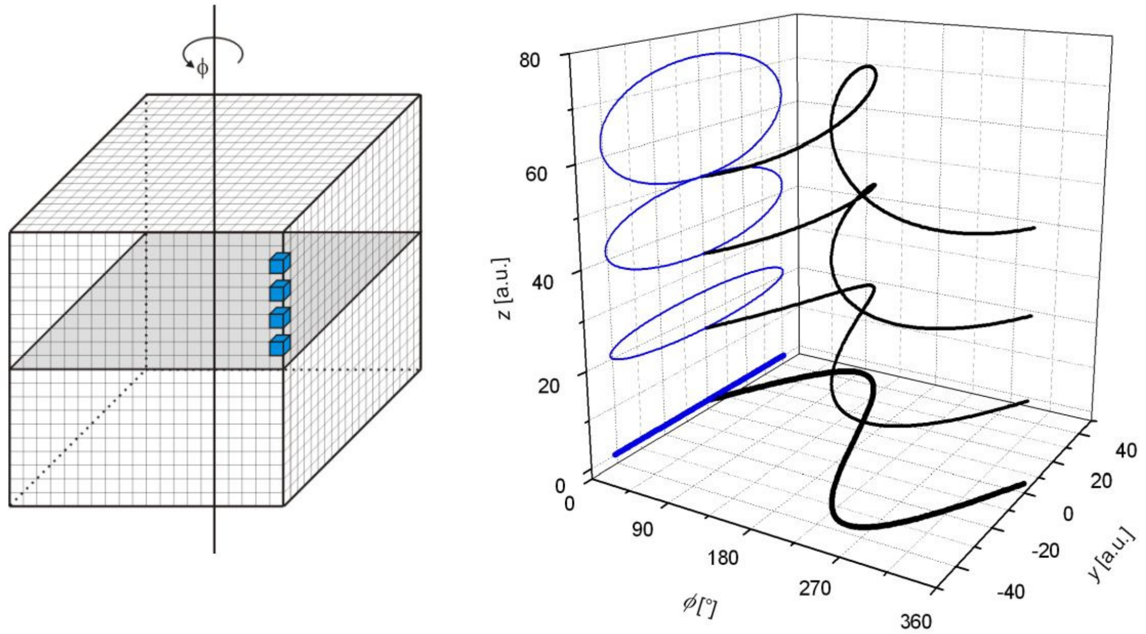

Figure 1. Voxel model (left), the according spatial trajectories (black lines) and their projections (blue lines) towards the detector in the z-y-plane (right)

When computing trajectories of voxels it is necessary to know not only the horizontal and vertical position at the detector but also to take into account the effective voxel size (magnification). In the case of cone beam projection one detector line outside the central plane contains not only information on one plane of the reconstruction matrix perpendicular to the axis of rotation. Therefore, any long range filtering in one detector line is compulsory erroneous and produces artefacts in the reconstruction. These errors increase with the object's size and distance from the central plane of projection. On application of a short range filter these errors are minor and can be avoided. DIRECTT integrates along the trace of reconstruction voxels and takes into account the individual voxel by using local weights of the filtered projections. This resulting reconstruction includes errors as well, but we select a fraction of the 3D-reconstruction only (e.g. only density values greater than 70% of the maximum density are used).

This partial reconstruction will be projected and afterwards subtracted from the as-measured data set (density sinogram).

By doing so, artefacts in the reconstruction with usually minor amplitudes can be reduced significantly. Any new reconstruction is computed from projections containing less density and so producing less artefacts. The projection of the partial reconstruction has to be calculated thoroughly and, if necessary, take into account detector anomalies and focal spot size. This step can solely be properly computed for projections. Any reconstruction will always be an approximation.

Simulation of a five-step pyramide

In order to demonstrate the quality of reconstruction it proves best to use a simulation ,where detector response, focal spot size and noise can be considered to be ideal. The pyramide (Fig. 2) was projected in cone beam geometry through 360 degree of rotation.

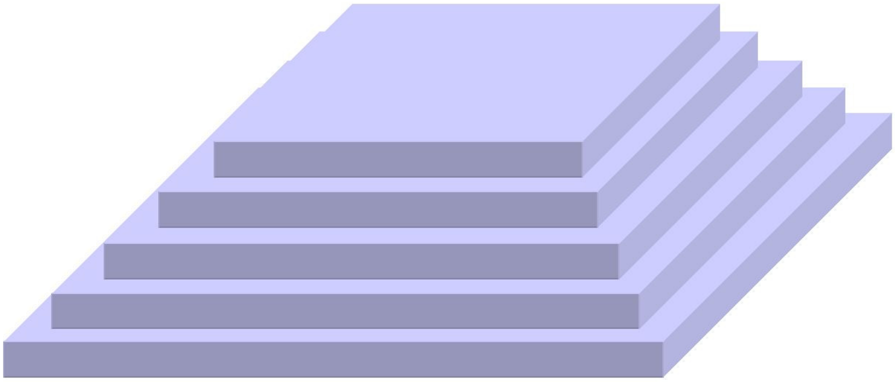

Figure 2. Visualisation of the model pyramide

The central plane of projection was chosen to be the top surface and the rotation axis in the center of gravity of the pyramide. Fig. 3 displays cross sections of reconstructions: FDK (bottom) and DIRECTT after 15 iterations (top). While in the lower part the artefacts increase from top to bottom, in the upper part they are strongly suppressed. This can be seen even better in Fig.4, where the difference of model and reconstruction is displayed. In the DIRECTT difference (top) the vertical edges are almost beyond recognition due to the sharp edged reconstruction. In contrastthe FDK reconstruction (bottom) exposes severe edge artifacts.

Figure 3. Cross sections of DIRECTT (top) and FDK (bottom) reconstructions

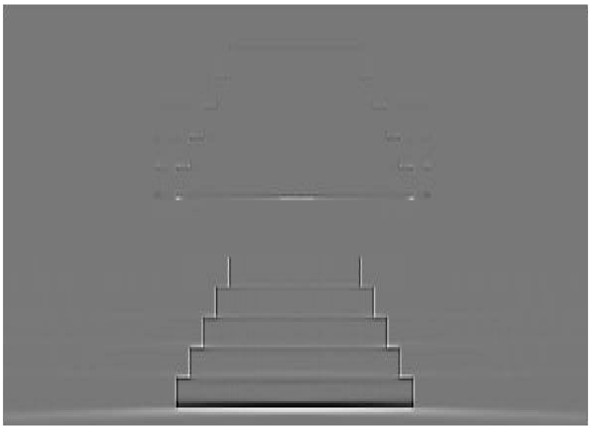

Figure 4. Respective residual differences to the original model

Reconstruction of a spherical calotte plate

A spherical callote plate made of Zerodur (glass ceramics)is at first investigated by tactile metrological measurements at the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig. From X-ray data measured at BAM two reconstructions had been achieved with FDK and DIRECTT algorithm which were digitally registered with VGStudio MAX (Volume Graphics GmbH) .

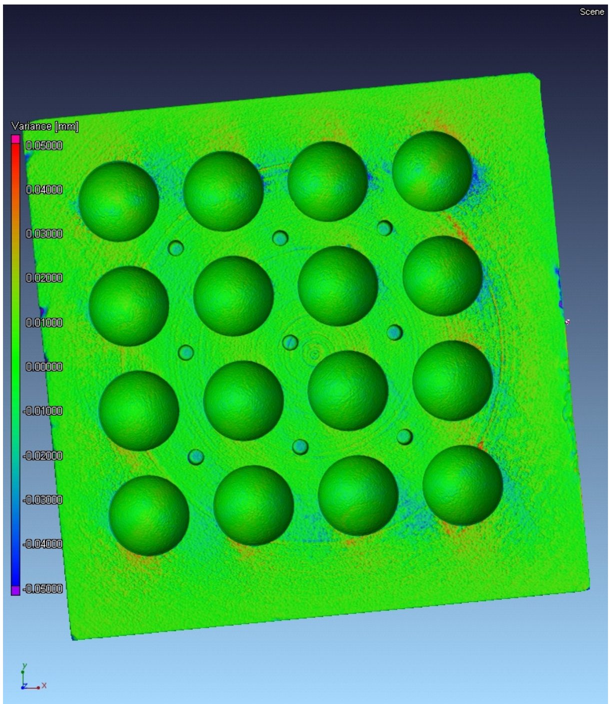

Figure 5. FDK deviations from tactile metrology data

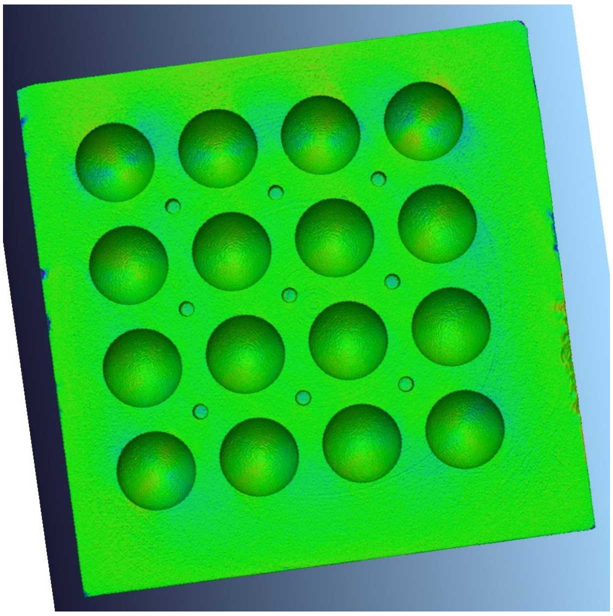

Figure 6. DIRECTT deviations from tactile metrology data

The differences to the tactile data are displayed in pseudo-colour. As shown with the step pyramide already, the artefacts outside the central plane are significantly larger in the FDK reconstruction (fig.5) compared to DIRECTT (fig.6). Furthermore, the differences in the small cylindric holes are less pronounced in fig.6. However, some deviations in the inclined calotte walls are slightly larger in fig.6 compared to fig.5. It might be that precise homogeneous voxels cannot approximate spherical surfaces very well, because a continuously curved surface is by no means properly described as a polyhedral surface. Computing sub-voxels of even smaller size might improve the results (under preparation). Because of reconstructed edge steepness being positional dependent, the registration has to be questioned as well.

Summary

In order to test the reconstruction quality of the DIRECTT algorithm a voxel model of a five-step pyramid is projected and reconstructed. Compared to the FDK reconstruction there is clear evidence for reduced artefacts, especially outside the central plane. This is also achieved by a real measurement of a spherical calotte plate, except some residual artefacts from inclined surfaces. It is assumed that they will disappear by reconstruction of sub-voxels of smaller size within the next approach.

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Acknowledgements
The authors would like to thank J. Goebbels and A. Staude (BAM) for their splendid support. Financial support by the Bundesministerium für Forschung und Bildung (BMBF), Germany, under contract no. 03SF0324B is gratefully acknowledged.