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3D computed tomography using a microfocus X-ray source: Analysis of artifact formation in the reconstructed images using simulated as well as experimental projection data

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Abstract

The scope of this contribution is to identify and to quantify the influence of different parameters on the formation of image artifacts in X-ray computed tomography (CT) resulting for example, from beam hardening or from partial lack of information using 3D cone beam CT. In general, the reconstructed image quality depends on a number of acquisition parameters concerning the X-ray source (e.g. X-ray spectrum), the geometrical setup (e.g. cone beam angle), the sample properties (e.g. absorption characteristics) and the detector properties. While it is difficult to distinguish the influence of different effects clearly in experimental projection data, they can be selected individually with the help of simulated projection data by varying the parameter set. The reconstruction of the 3D data set is performed with the filtered back projection algorithm according to Feldkamp, Davis and Kress for experimental as well as for simulated projection data. The experimental data are recorded with an industrial microfocus CT system which features a focal spot size of a few micrometers and uses a digital flat panel detector for data acquisition.

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1. Introduction

X-ray inspection is well established as a valuable tool in nondestructive testing (NDT). Concerning X-ray radiography with high spatial resolution, the state of the art are microfocus inspection systems with flat panel imaging (FPI) detectors replacing image intensifier systems. They are widely used for testing small mechanical or electronic components. By cone beam projections, a high magnification is achieved and the spatial resolution ranges down to about 1 μm.

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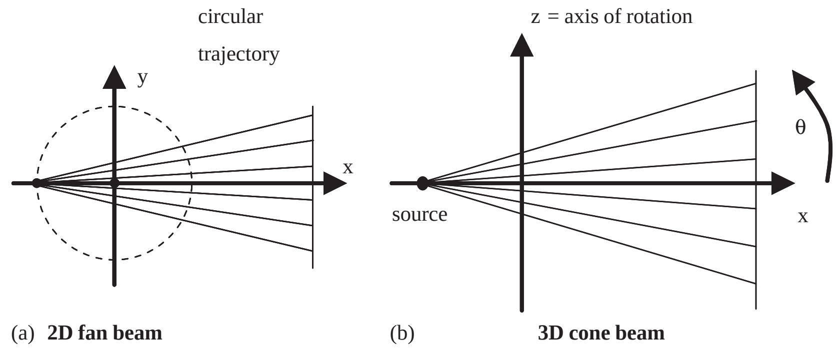

Fig. 1. (a) Scanning geometry for 2D fan beam FBP (top view); (b) extending the fan to a cone (side view, y axis omitted for simplicity).

In order to get full volumetric information, we use computed tomography (CT). A number of different projections are collected by a circular source trajectory and then reconstructed using the algorithm by Feldkamp, Davis and Kress (FDK) [1]. This algorithm is based on 2D filtered back projection (FBP) and is known to be robust and reasonably fast, but the algorithm does not give exact results. It turns out that for large cone beam angles (see Fig. 1), artifacts arise, for our phantom typically rhombic shaped. We will illustrate later on that these artifacts are related to missing information in Fourier space.

As there are a number of additional artifacts in the experimental case, we will identify them by simulation. In contrast to CT using synchrotron radiation, the spectrum of an X-ray CT source is polychromatic, which causes beam hardening artifacts in the reconstructed images. The shape and the absorption characteristics of the object will influence the formation of these artifacts as well as the X-ray spectrum. Another kind of artifacts results from the implementation of filtering and zero padding in the data processing. Furthermore some imperfections of FPI detectors and various scattering effects will produce additional artifacts which we have not modeled in the simulation.

2. Review of the FDK algorithm

We want to briefly review how the FDK algorithm is set up on 2D FBP. For 2D fan beam geometry, FBP reconstructs the original volume exactly. Only the detector pixel spacing (Nyquist theorem) and the angular increment need to be small enough.

In Fig. 1(a), a point source moves on a circular trajectory and a line detector follows on the opposite side. The axis of rotation is perpendicular to the 2D plane. So far a 3D object could be reconstructed slice by slice.

With the FDK algorithm, a cone beam geometry and a two-dimensional flat panel detector is used instead. This has the advantage that the magnification is isotropic, i.e. the magnifications along the axis of rotation and perpendicular to it are equal. The cone can be thought of as a series of fan beams from one point source which are tilted out of the 2D plane, Fig. 1(b). The inclination angle between a tilted fan and the central plane will be denoted by θ. The circular source trajectory is not changed and the central plane $z = 0$, i.e. $\theta = 0$, is reconstructed exactly. The other planes are intersected by tilted fan beams and the FDK algorithm computes an approximate 2D FBP [1] only. It neglects the inclination angle which causes rhombic-shaped artifacts, like in our results shown later.

The reason for this kind of artifacts is the partial lack of information using a cone beam angle $\theta > 0$. This situation can be explained considering a special kind of tomographic modality, the digital tomosynthesis (DTS) [2]. Consider a central plane in the same place as in the previous example and a circular source trajectory which is shifted above