Adaptive Zooming in X-ray Computed Tomography

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ABSTRACT

In computed tomography (CT), the source-detector system commonly rotates around the object in a circular trajectory. However, such a trajectory does not allow to exploit a detector fully when scanning elongated objects. In this paper, a new approach is proposed, in which the full width of the detector is exploited for every projection angle. This approach is based on the use of prior information about the object's convex hull to move the source closer to the object, obtaining more detailed information from particular projection angles. Experiments show that this approach can significantly improve reconstruction quality.

1. INTRODUCTION

In most X-ray computed tomography (CT) acquisition setups, the source-detector system rotates around the object in a well-defined and geometrically simple manner. In micro-CT imaging, for example, a circular source-detector trajectory is by far the most popular one. The radius of such a trajectory is often chosen so as to avoid truncation in the acquired projections. That is, the radius is chosen large enough so that for each angle the full projection of the object is captured by the detector. However, for elongated objects, a circular trajectory does not allow to exploit the detector optimally. In (Xia *et al.* 2008), it was shown that non-planar trajectories yield visually better reconstructions than circular trajectories in applications of tomosynthesis to breast imaging. In single photon emission computed tomography (SPECT), non-circular orbits have been shown to reduce uniformity artefacts (Todd-Pokropek 1983), to improve resolution (Eisner *et al.* 1988, Pan *et al.* 1997), contrast, edge definition, and uniformity (Gottschalk *et al.* 1983). It was also noted, that in certain cases in SPECT elliptical orbits can produce reconstructions with undesirable artefacts, introduced by significant regional nonuniformity (Maniawski *et al.* 1991). Despite these facts, the use of non-conventional trajectories is still almost unexplored.

To improve reconstruction quality, a new approach is proposed in which the full width of the detector is exploited for every projection angle. To this end, projections are taken from the smallest possible distances to the object, while avoiding truncation. This is achieved by calculating the source position for every projection angle based on the information about the convex hull of the object. The proposed approach is integrated into an algebraic reconstruction framework, while its use with analytical reconstruction methods needs a rebinning procedure that still has to be developed. Possible applications of this approach include devices with flexible acquisition geometries, mobile tomography, and tomography of the objects with substantial differences in their dimensions, such as electronic components.

In our simulations, the convex hull of the object is used as a source of information about the geometry of the object. In practice, an approximation of the convex hull of the object can be built from a preparatory scan used to plan the scanning procedure or from CAD models (for industrial objects) (Laurentini 1994).

2. APPROACH

The idea of the proposed variable distance approach (VDA) is to acquire a projection for a particular projection angle by placing the X-ray source as close as possible to the object, while avoiding truncation. In contrast to a circular trajectory approach (CTA), which keeps the source-object distance constant, VDA allows to fully use the detector and obtain more information from this angle. To calculate the smallest possible source-object distance, prior information about the object must be exploited. In our experiments, we use the convex hull of the object to calculate this distance.

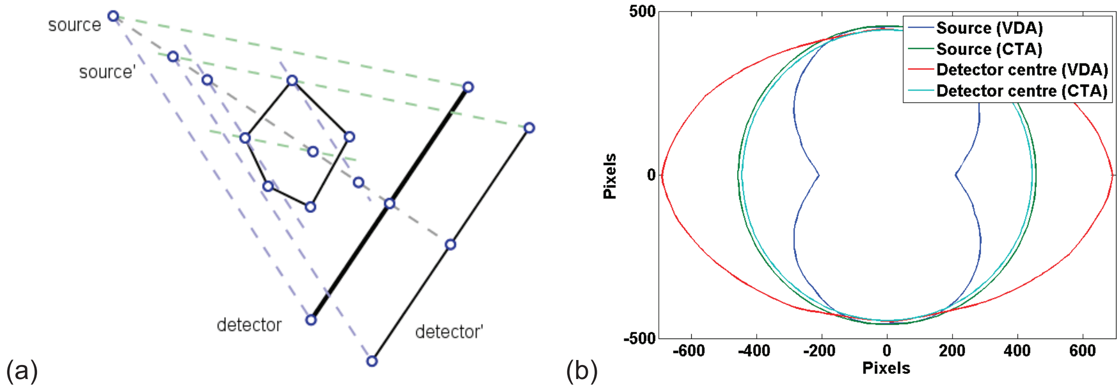


Figure 1: *Geometry of trajectory calculation in VDA (a) and the trajectories for the simulation experiment (b)*

Consider a fan-beam CT setup with a circular trajectory, a linear detector array and a fixed source-detector distance (Figure 1(a)). For each projection angle and for every vertex in the convex hull, lines are constructed, parallel to the lines connecting the source and the detector edges, and containing this vertex. Among all the intersections of the constructed lines with the line containing the source and the centre of the detector, find the one that is the most distant from the centre of rotation. This point is the closest possible to the object source position from which the object will be imaged without truncation. Repeating this procedure for every projection angle yields the desired trajectory.

3. EXPERIMENTS

3.1. Simulation experiments

Simulation experiments were run using a Siemens star-like phantom (Figure 2(a)) to demonstrate the proposed approach. Grey values of the phantom lie in [0,255]. The phantom was downscaled by a factor *a=2* with bilinear interpolation resulting in image of 128×128 pixels of unit size while the original phantom had 256×256 pixels of *1/a* unit size. A number of *m* equiangular fan beam projections were computed from the original phantom using Joseph's projection method (Joseph 1982) and then downsampled by a factor *a=2* in the radial direction summing the photon counts for *a* neighbouring detector bins. The source trajectory for VDA was calculated as described in Section 2 (Figure 1(b)). In CTA the source was placed at the distance corresponding to the maximum distance used in VDA. The reconstructions on 128×128 pixels of unit size reconstruction domain were built with 200 iterations of the Simultaneous Iterative Reconstruction Technique (SIRT) (Gregor and Benson 2008). Values outside the convex hull were not involved in the reconstruction.

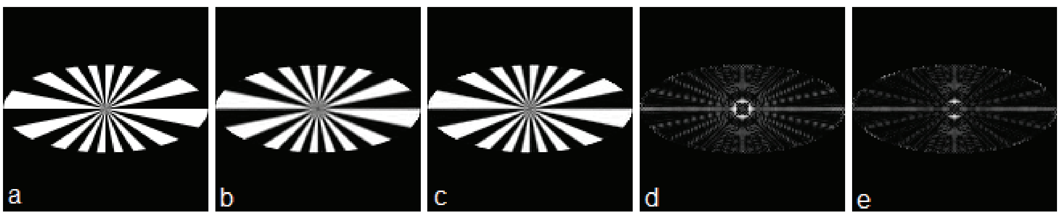


Figure 2: *The reconstructions of the phantom (a) with CTA (b) and VDA (c) using 200 projections and the corresponding absolute difference images (d, e) (windowed to [0, 150] for better visual contrast)*

The quality of the reconstructions was assessed by calculating the mean squared errors (MSEs) over the values inside the convex hull. The first row of Table 1 shows the quantitative MSE results. Figure 2 shows the reconstructions of the phantom using CTA and VDA along with absolute difference images. From the presented results one can conclude that VDA can produce the reconstructions which are better both visually and in terms of MSE than CTA.

In order to evaluate the proposed approach in a more realistic situation, the experiment was extended with noise simulations as described in (Guan and Gordon 1996). Ten noisy sets of projection data were obtained (the values $N=10^5$ and $N=10^6$ represent the number of incident photons for CTA and the corresponding number of photons for VDA was calculated taking into account the source-object distance). For each noisy projection dataset the reconstructions were built and the mean values of MSE of these reconstructions are shown in last two rows of Table 1, from which one can observe that VDA yields better results in the presence of noise than CTA.

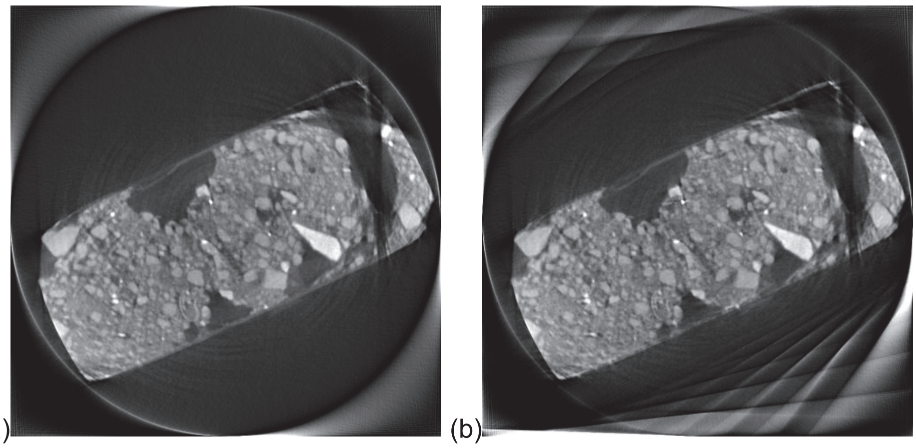
Table 1: *MSE of the reconstructions of the phantom*

	CTA, m=30	**VDA, m=30**	**CTA, m=200**	**VDA, m=200**
Noiseless	4.87×10^3	4.14×10^3	547	334
$N=10^6$	4.89×10^3	4.18×10^3	558	349
$N=10^5$	5.21×10^3	4.64×10^3	681	495

3.2. Real experiment

To mimic a tomographic system with variable source and detector position, the following experiment was conducted using a desktop micro-CT system SkyScan-1072 (Bruker-MicroCT, Belgium). A plastic capsule with a diameter of 7 mm and a length of 15 mm filled with a mixture of sand and glue was used as an elongated object. For this object, seven full-angle datasets were obtained, each containing 533 images of 1024×1024 pixels, with the source-object distances ranging from 106.10 to 185.64 mm. The source-detector distance was equivalent to 371.28 mm.

In order to simulate fan-beam scanning setup the central lines (the lines containing the optical axis) of the projections from the dataset obtained from the biggest distance were used during the reconstruction with CTA. Based on the CTA reconstruction, an approximate convex hull for VDA was created. In VDA for each projection angle the closest possible distance was calculated for this convex hull and a projection was chosen from the dataset obtained from the smallest distance bigger than or equal to the calculated one.



(a) (b)

Figure 3: *Reconstructions of the capsule with sand with CTA (a) and VDA (b) (windowed to [-0.005, 0.03] for better visual contrast)*

In an ideal setup the central line of the chosen projection would also be used for VDA reconstruction. However, in the given device the movements of the object stage were not (and were not designed to be!) µm-precise, and the object can be shifted along the rotation axis or tilted during such movements causing changes in volumes of the object being imaged by the same detector line from the various distances. In order to partially compensate for these shifts, several slices neighbouring to the central one were reconstructed. Then the slice which was the visually closest to the central slice was chosen and the corresponding lines in the projections chosen by VDA were used for the VDA reconstruction.

Both the CTA and VDA reconstructions were performed on the 1024×1024 pixels reconstruction grid with a pixel size of 17.09 µm using 700 iterations of SIRT. Figure 3 presents the reconstructed images. From these reconstructions it is not possible to conclude that the VDA reconstruction is better than CTA. Three reasons can introduce errors in the VDA reconstruction preventing it from performing notably better than CTA:

- possible shifts and tilts of the object during the movement of the object stage between scans (as described above) which cannot be fully compensated in VDA and which are completely absent in CTA;
- the compensation procedure applied assumes choice of non-central lines of the projections, which causes the deviation of the geometry from being fan-beam-like;
- the change of the source-object distance results in imaging of different volumes of the object by a given detector line (even in the absence of previous reasons) as the slice thickness depends on this distance. The resulting reconstruction contains a composition of thinner and thicker slices, possibly making the spatial resolution anisotropic. However, the slice thickness is intrinsically taken into account in a three-dimensional extension of the approach.

Despite these reasons, the VDA reconstruction looks similar to the CTA reconstruction, adequately representing the object features.

4. CONCLUSION

In this paper, the variable distance approach (VDA) for CT scanning was proposed. This approach is based on the modification of the classic circular trajectory according to prior information about the object's convex hull which is used to take projections from as close as possible distances to the object for every projection angle providing that the truncation is avoided. Our simulations showed that the proposed VDA approach can lead to more accurate reconstructions with lower errors, even in the presence of noise. In real experiments, image quality improvement is less obvious, mainly because of mechanical instabilities during scanning, which will be accounted for in future research.

5. ACKNOWLEDGEMENTS

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