Comparing CT Reconstruction Algorithms Regarding Cone–Beam Artifact Performance

Clemens Maaß1, Frank Dennerlein2, Frédéric Noo3, Marc Kachelrieß1

1Institute of Medical Physics, University of Erlangen-Nürnberg, Erlangen, Germany
2Siemens AG, Healthcare Sector, Forchheim, Germany
3UCAIR, Department of Radiology, University of Utah, Salt Lake City, UT, USA

Purpose:
With increasing cone angle the cone–beam artifacts in x-ray CT become more and more prominent. It is well known that cone-beam CT (CBCT) does not satisfy the data completeness condition for exact image reconstruction and therefore allows only for approximate image reconstruction [1]. Additionally, in clinical C–arm CT often only a short scan with less than a full rotation can be acquired, which may be motivated by reasons like temporal resolution or for technological reasons (figure 1). Nevertheless, CBCT plays an important role in medical imaging as almost every commercially available clinical CT scanner acquires cone–beam data. As a special case, in flat detector CT usually the complete volume of interest (VOI) is illuminated and the cone angle approximately equals the fan angle. A large cone angle brings advantages like higher efficiency of the x–ray tube and lower scan times. As a consequence of these advantages in scanner design, the number of detector rows will further increase in future systems. The resulting larger cone angle will cause even more severe artifacts. In this work different methods to reconstruct short scan CBCT data are compared regarding their cone–beam artifact performance and their computational load.

Materials and Methods:
Two gold standard algorithms (short scan FDK and SART, figure 2) are compared with two algorithms that are designed to reduce cone–beam artifacts. The short scan FDK algorithm is the standard CBCT reconstruction algorithm extended by the rawdata weighting proposed by Parker for short scans [2, 3]. The factorization approach (figure 3), which is described in detail in reference [4], solves the problem of short scan CBCT reconstruction by separating the reconstruction into numerous, independent 2D inversion problems. These problems are numerically solved by an iterative constrained steepest descent method. The cone–beam artifact reduction (CBAR) method is newly proposed here (figure 4). It uses the ideas of reference [5] and is described in detail in the following paper. The method starts with an initialization image (e.g. short scan FDK) and then uses forward projection and a filtered backprojection to calculate an update image.

Results:
The methods are compared via visual inspection in figures 5 and 6 using two different phantoms. Further, in the Defrise disk phantom reconstructions the CT–values of the disk at the border of the FOM are quantitatively evaluated. Those results are presented in figure 7. Profiles through the disk phantom along the scanner’s rotation axis are presented in figure 8. It is apparent that the computationally cheap short scan FDK method yields the worst results regarding the image quality as disks at high cone angles cannot be separated in the reconstruction. The iterative methods (SART and CBAR) yield the best image quality regarding the cone–beam artifacts, however, their computational load disqualifies those methods for clinical use. The only method that combines low cone–beam artifacts with low computational load is the factorization approach.

Conclusion:
The results show that iterative methods yields the best results regarding cone–beam artifact performance. The factorization approach shows the best trade–off between cone–beam artifact performance and computational load.

Acknowledgment:
This work was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant KA 1678/4–1.

Figure 1: We are dealing with short scan cone–beam CT data. The influence of the cone–beam geometry compared to a parallel geometry is illustrated at the bottom of the figure.

Figure 2: The short scan FDK algorithm and the SART algorithm are standard methods for CT image reconstruction.

Figure 3: The factorization method is designed for CBCT reduction with low cone–beam artifacts.

Figure 4: The CBAR method uses analytic image reconstruction within an iterative update formula that is designed as fixed point equation.

Figure 5: Reconstruction results of the Defrise disk phantom comparing four different short scan CBCT reconstruction methods.

Figure 6: Reconstruction results according to figure 5 but using the Forbild thorax phantom.

Figure 7: Quantitative evaluation of the Defrise disk phantom results and theoretical estimation of the computational load.

Figure 8: Profile evaluation of the Defrise disk phantom results. All methods except the short scan FDK allow a clear separation of the all disks.