Segmented Multiple Plane Reconstruction - A Novel Approximate Reconstruction Scheme for Multislice Spiral CT

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***Abstract*—A new reconstruction scheme for multirow spiral CT is described and results are presented. The spiral path is decomposed into small, overlapping segments which are used for a separate convolution and backprojection yielding a stack of segment images which contain only data of a partial scan. These segment image stacks are, in a second step, reformatted to the requested planes. In a third step, the reformatted segment images are added to obtain full images.**
The main benefit of the proposed algorithm is the superior image quality. The limit of the algorithm has not been probed; a 64-row dataset with pitch 80 has been reconstructed with excellent image quality.
***Index Terms*—Approximate reconstruction, cone artifact, spiral CT, multislice CT.**

I. Introduction

A. Basic idea

Lately, a new class of reconstruction algorithms has emerged which further extend the domain of approximative reconstruction for multislice spiral CT.
The underlying idea is the following simple observation: if it was possible to find an image plane so that the focus does not leave this plane during a half turn of the spiral, we would be able to choose (or interpolate), for each projection angle and each fan parameter, rays that are fully contained in the image plane. A simple 2D reconstruction of these rays would yield an *exact* reconstruction of this image plane. Of course, we know that this is impossible for a spiral scan path, but it turned out fruitful to take this idea as a starting point for approximations. All of the algorithms described shortly in the following are based on this idea.

B. Advanced Single Slice Rebinning (ASSR)

The Advanced Single Slice Rebinning (ASSR) reconstruction method, ([1]-[3]) tries to match image planes directly to a π segment of a spiral path. Kachelrieß et al. reconstruct these images from overlapping π intervals and reformat the tilted images to axial planes in a second step. The images are reconstructed from overlapping scan intervals of π. The main drawback of the ASSR algorithm lies in the fact that it is useful only for the maximum pitch (approximately 1.4 times the number of rows for typical CT scanners) or, alternatively, requires severe detector masking by software for lower pitch values resulting in poor dose usage. Even at the optimum pitch, the dose usage is only 70 %. Another drawback of ASSR is that the average distance of the focal spot from the tilted image plane - which is a measure of the quality of the approximation to the basic idea described in section A - increases with pitch, hence degrading image quality.

C. Adaptive Multiple Plane Reconstruction (AMPR)

The Adaptive Multiple Plane Reconstruction (AMPR) scheme [4] solves the pitch restriction problem of the ASSR by introducing a second tilt angle, with a tangent to the spiral as the hinge line. By reconstructing, for each of the overlapping reconstruction intervals, several images, rotated by different angles around this hinge, a much larger fraction of the dose can be used.

D. Segmented Multiple Plane Reconstruction (SMPR)

The Segmented Multiple Plane Reconstruction (SMPR) algorithm presented here goes one step further: it uses only a small *segment* (typically less than one eighth of a full turn) of the spiral to reconstruct a *booklet* (stack) of *segment image pages*. Since the segments are small, the pages of a booklet can be matched almost perfectly to the spiral path. Then, for all segments of a π interval, all booklets belonging to a segment and its complementary segment *in all rotations* are reformatted to the desired (e.g. axial) planes. In a last step, images from segments of a π interval are combined to a full image. Essentially, the steps of reconstruction (convolution and backprojection) and z-interpolation are interchanged with respect to conventional multislice spiral algorithms.
In principle, the match of the pages to the spiral path will be the better the shorter the segment is. For a 16-row scanner, we found that eight segments are sufficient for good image quality. The 64-row reconstructions were done with 32 segments.

II. Algorithm

A. Segment images

The first step is the reconstruction of segment images. For each of the segments, a fraction of $2\pi/N_{seg}$ (N_{seg} is the number of segments per rotation) of one rotation (plus some

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overlapping to provide smooth transitions from one segment to the next) is used to reconstruct a *booklet* of at least N_{rows} (the number of detector rows) pages. For each page, the rays closest to the image plane are selected for convolution and 2D-backprojection. Hence, we obtain per rotation a total of $N_{seg} \cdot N_{rows}$ segment images. The segment images are reconstructed with the finally desired field of view. It can be shown that, by doing this, the information available in the data is used almost perfectly if N_{seg} is sufficiently large. Figure 1 gives an impression of a typical segment image.

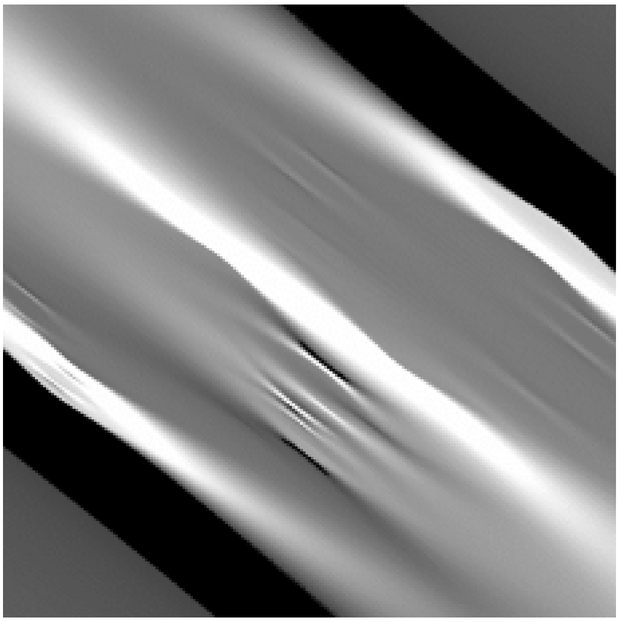

Fig. 1. A typical segment image (N_{seg}=32).

B. Stack reformation

The next step is to reformat the pages of a segment and its complementary segment from all rotations to the desired (e.g. axial) image planes. This can be done in a pixelwise fashion, in z direction only. In this step, the final image slice thickness can be adjusted by changing the width of the weight function used for reformation.

The location of the segment pages is shown in Figure 2 for the case of N_{seg}=N_{rows}=6. The pages contributing to one of these reformatted segment images are shown in the same shade.

C. Segment adding

The final step is a simple adding of the reformatted segment images of at least one half turn to a complete image.

III. Transition to Feldkamp algorithm

A theoretically interesting aspect of the SMPR approach is that, by using smaller and smaller segments, we finally end up with filtering and backprojecting only one (parallel) projection at a time onto planes which are spanned by the projection vectors of one detector row. Taking into account the second step of reformatting to axial planes and the final step of combining segments it becomes clear that this is equivalent to a spiral version of the Feldkamp algorithm which involves a filtering parallel to the spiral path followed by a 3D backprojection. Hence, the SMPR algorithm provides a smooth transition from an algorithm which utilizes a 2D-backprojection to a 3D-backprojection algorithm. A byproduct of this consideration is that a canonical filter direction for the filter step of the spiral Feldkamp reconstruction is obtained.

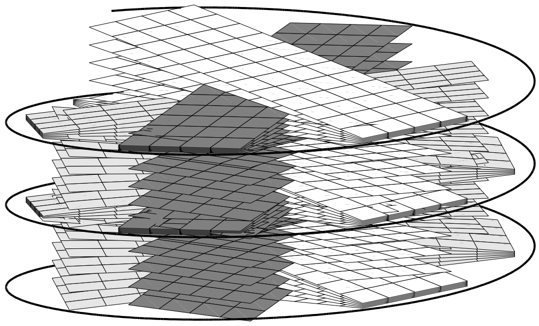

Fig. 2. Demonstration of the spiral path together with some sample booklets. Pages which are reformatted together are shown in the same shade.

IV. Results

To test the algorithm we used the simulation program DRASIM (Siemens Medical, Forchheim) to produce a test data set of a thorax phantom (geometry definition by Katja Sourbelle, FORBILD project) for a fan-beam scanner with 64x1mm rows and a pitch of 80. The data were reconstructed with the SMPR using N_{seg}=32 (Figure 3) and, for comparison, also with the AMPR algorithm (Figure 4).

The SMPR image is obviously almost free of artifacts whereas the AMPR image exposes severe artifacts, particularly near the strongly tilted ribs.

V. Conclusion

A substantially improved approximative reconstruction algorithm for multislice spiral CT has been presented. While the limits of the algorithm have not yet been probed, results are excellent. A drawback of the algorithm is the large amount of intermediate segment images which has to be handled during the reformatting step.

From the theoretical point of view, an interesting aspect of the algorithm is that it provides a smooth transition from a 2D reconstruction approach to a 3D Feldkamp-type spiral algorithm.

Fig. 3. Typical axial image of a thorax phantom at pitch 80, reconstructed with SMPR using 32 segments. The field of view is 400 mm; the display window is 200 HU. Almost no artifacts are visible.

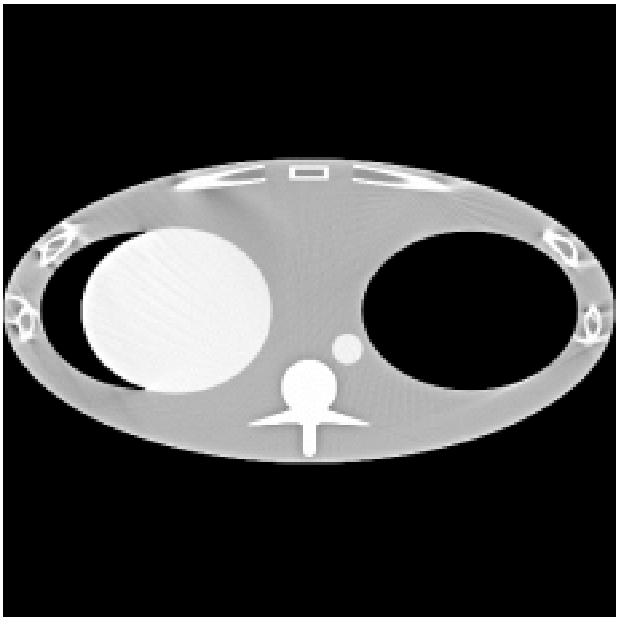

Fig. 4. Axial image of a thorax phantom at pitch 80, reconstructed with AMPR. The field of view is 400 mm; the display window is 200 HU; same slice location as figure 3. Severe artifacts are visible, particularly near the ribs.

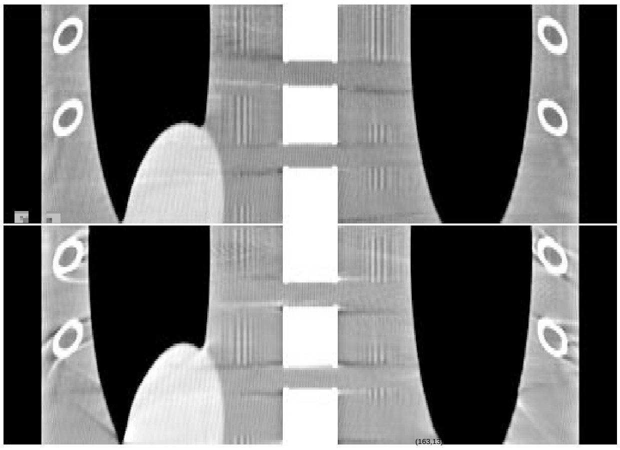

Fig. 5. MPRs of stacks of axial images, thorax phantom at pitch 80. Top: reconstructed with SMPR using 32 segments, bottom: reconstructed with AMPR. Display window 200 HU. Again, the SMPR images are almost free of cone artifacts while severe artifacts are visible in the AMPR image. The fine vertical streaks are spiral artifacts which are independent of the type of reconstruction.

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