A new algorithm for ring artifact reduction in cone-beam computed tomography: preliminary results

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Purpose

High resolution micro CT images are often corrupted by ring arti facts that hinder quantitative analysis. These artifacts are caused by imperfections in detector elements which introduce differences in gain at specific positions in the detector array. Removal or a significant reduction of such artifacts is highly advisable. A common approach is the flat field correction, which involves the acquisition of a long study without any sample in the scanner. However, this method is often not sufficient to completely eliminate the artifacts, especially if the response of the detector elements depends on the incident X ray flux characteristics that may change between acquisitions.

Several algorithms for ring artifact correction have been proposed. These methods can be divided basically into two groups: the ones that work in the image space, generally involving a conversion to polar coordinates, and those which work on the projection space.

Both in the projection space and in the polar coordinate domain of the reconstructed image the ring artifacts appear as straight lines.

Most algorithms try to detect these straight lines either in image domain or in the Fourier domain where the frequencies along the horizontal direction and low frequencies along the vertical direction.

An interesting approach was implemented by Sijbers et al., who transformed the reconstructed image into polar coordinates and created a correction vector calculated from homogenous areas of the image. This procedure showed good results but at the cost of some degradation of image quality and a high computational cost, derived from the interpolations involved in the transformations between Polar and Cartesian domains.

In this work we present a new method for ring artifact compensation, suitable for cone beam data. Starting from the idea of Sijbers et al., we have developed an improved procedure that operates on the projection data before the reconstruction and does not require interpolations, thus avoiding image degradation and reducing the computational burden. Results on phantoms and rodent studies are presented.

Material and methods

In cone beam CT scanners the 2D images corresponding to each projection angle can be piled up to create a 3D dataset The inhomogeneous sensitivity of the detector cells produces straight lines along the angular direction in that 3D projection data set. The FDK reconstruction algorithm turns each of these lines into rings which appear in different slices in the reconstructed image. These lines may not be very conspicuous in the projection data, especially when the differences in sensitivity of the detector cells are slight, thus hindering their automatic detection.

The algorithm proposed works on a 3D projection set of dimensions (N_r x N_z x N_F). For each projection slice of dimensions Nr x NF the procedure is applied as follows:

1) A window, W, of size N_W x N_F is moved over the projection slice.

For each position of the window, a homogeneity test is performed for each row by:

> 1a. A smoothed version of the row is subtracted, generating a vector H_V, vector with the high frequency components containing noise, ring artifacts and some residual high frequencies of the object.
>
> 1b. Those N rows whose standard deviation is above a threshold T are assumed to contain ring artifacts and not only noise, being selected for the following step.

2) These N rows selected are piled up in a matrix, H_m, with dimensions N_W x N. A correction vector C_V (that will have N_W elements) is then calculated from this matrix by taking the median along the vertical direction. Each point of C_V represents an additive correction factor for a pixel inside the window in the actual position. Each pixel may have received more that one candidate correction factor at the end of the process, given that the window W overlaps as it moves through the projection slice.

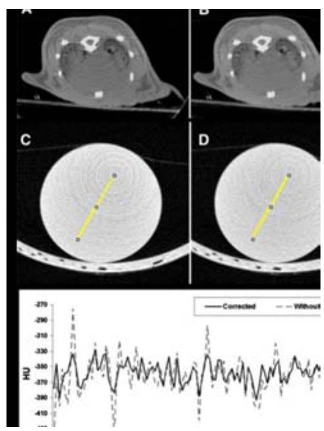

Fig. 1 Top: Axial slices in a mouse study and in the cylinder study (left panel: ring contaminated original images, right panel: images after ring artifact correction. Bottom: Radial profile corresponding to the yellow line in C and D The final correction factor selected for each pixel will be the one contained in the C_V that was generated from the biggest H_m (higher number of rows that passed the homogeneity test).

Values for the parameters N_W and T are calculated from the projection data as: N_W Nr/20 and T std_dev (H_V) * 0.5). The factors 20 and 0.5 were heuristically determined and seemed to be adequate for all the images tested.

We have tested the algorithm on rodent studies and a homogenous cylinder. The studies were acquired with the CT subsystem of an eXplore Vista PET/CT scanner (General Electric Healthcare) and reconstructed with an FDK algorithm. Image enhancement achieved by the correction procedure was qualitatively assessed by visual inspection. Artifact reduction was also quantified on profiles drawn along the radial direction in homogeneous areas of the reconstructed image.

Results

The visual analysis showed a noticeable reduction of the ring artifacts both in rodent and cylinder studies. The reduction achieved in standard deviation of the radial profiles in homogeneous areas was about 33% (Fig. 1).

Conclusions

The algorithm developed showed satisfactory results when tested with real CT data. The main advantages of our algorithm with respect to others previously reported are:

• It works on the projection data prior to reconstruction, avoiding the interpolations required by previous algorithms.

• Image borders are preserved, as the algorithm is not based on low pass filtering.

• It is completely automatic.

• It provides a correction image for the projection data that can be applied to different reconstructions of the same dataset, without having to repeat the whole process.