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AN EFFICIENT RING ARTIFACT CORRECTION METHOD FOR A FLAT-PANEL DETECTOR BASED MICRO-CT IMAGES

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ABSTRACT

The most common mechanical artifact in micro computed tomography (CT) is ring artifacts. The ring artifacts are caused by shifts in output from individual detectors or sets of detectors, which cause the corresponding ray or rays in each view to have anomalous values; the position of a ring corresponds to the area of the greatest overlap of these rays during reconstruction. These ring artifacts can seriously degrade the quality of CT images. Due to these ring artifacts, the CT images may not be diagnostically usable. In flat-panel detector based micro-CTs, the ring artifacts are hardly removed by the conventional flat-field correction method. This paper presents a novel method of removing ring artifacts in flat-panel detector based micro-CTs. The proposed ring artifacts removing method is based on image domain. At first the recostructed image having ring artifacts is converted into polar coordinates image. In polar coordinate image ring artifacts become line artifacts. Then line artifacts are corrected and finally the resulting corrected image is again transformed back into Cartesian coordinates image in which ring artifacts are significantly removed. We have found that the ring artifact correction method works well for various kinds of images.

Key words: *Flat-panel detector, micro-CT, polar coordinates, ring artifacts, sinogram*

INTRODUCTION

Ring artifacts in not a very new issue in the field of micro-CT, but in recent times it is an important issue for those who uses flat-panel detector for micro-CT imaging. A new generation of digital flat-panel detectors is now emerging. Recently the application of flat-panel detector in micro-CT system has attracted new awareness. The advantages of the flat-panel detector in a micro-CT over other type of detectors are manifold. The flat-panel detectors have many advantages such as large-area detection, thin structure, no geometrical distortions (Kim *et al.,* 2003, Ning *et al.,* 2000). Since the flat-panel-detector technology is fast growing by the needs of mass production, availability and low cost are other merits in a micro-CT. However, flat-panel detectors have some technical problems to be tackled. Large-area flat-panel detectors have more defective or bad pixels from initial manufacture and through the working life of the detector. Some of the bad pixels show a time varying nature hampering accurate corrections. The time varying nature of bad pixels makes their corresponding image pixels in a projection image to behave abnormally in signal gray level (Tang *et al.,* 2001). As a result, ring shape structure or ring artifacts occur in the reconstructed image.

A single detector element in a rotate-only tomographic system records transmission data corresponding to one particular ray at one particular position in the fan-beam through a complete rotation (Kumar and Ramakrishna, 2002). Therefore, all information on a circle in the reconstructed image around the center is

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given by one detector element. A defective detector element on the sensing device will give rise to what is called ring artifacts (Kumar and Ramakrishna, 2002). So if there is any defective or bad pixel of the detector, it will corrupt a single column in the projection data which makes ring shape structure or ring artifacts in the reconstructed image. Therefore efficient reduction of ring artifacts is an important issue for the image using micro-CT. In this paper, all experiment is done by using an indirect-detection CMOS (complementary metal-oxide semiconductor) flat-panel detector (C7943CP-02, Hamamatsu, Japan). The flat-panel detector is based on a matrix-addressed photodiode array fabricated by a CMOS process coupled to a CsI:Tl (thallium-doped caesium iodide) scintillator as an x-ray-to-light converter.

Ring artifacts, as the name implies, appear as rings superimposed on the original image structure. Ring artifacts are usually caused by detector response non-uniformity in CTs consisting of line or planar array detectors. Ring artifacts are caused by imperfect detector pixel elements as well as by defects or impurities in the scintillator crystals (Axelsson *et al* 2006, Ketcham and Carlson, 2001). Drifts in the detector element sensitivity in between white-field calibrations may also cause ring artifacts. Ring artifacts can also be generated from higher energy harmonics in the incident beam (Antoine *et al,* 2002). An error in an isolated view is mapped to a straight line in the back projection process. If the same error is persistent over a range of views, the tail portions of the lines are canceled, hence, a ring is formed when the neighboring views are closely placed (Hsieh, 2003).

In reconstructed images, ring artifacts appear as narrow rings or wide bands depending on how many detector elements have the spurious behavior. Full rings are generated only if a 360 degree data acquisition is used and half rings with 180 degrees acquisition (Ketcham, 2006). A number of ring artifacts correction algorithm have been proposed. A common method to reduce the ring artifacts is the flat-field correction (Antoine *et al*, 2002, Cloetens, 1999), where the images are corrected using a white image and a dark image. But this method often gives quite big residual ring artifacts especially when the image SNR is low. Ring artifacts correction method in the sinogram domain is presented in (Raven,1998, Boin, and Haibel, 2006). In (Raven,1998), they proposed a method for ring artifacts reduction by processing the recorded data numerically prior to the image reconstruction. They have used one dimensional Butterworth low-pass filter for removing ring artifacts. In (Boin, and Haibel, 2006), they have used moving average filter to remove line artifacts in sinogram. In this paper, an efficient method is introduced to remove full or partial ring artifacts.

MATERIALS AND METHODS

In this paper, an efficient algorithm is elaborated for the reduction of ring artifacts. A commercially available flat-panel detector (C7943CP-02, Hamamatsu, Japan) is used as a 2D digital x-ray imager in the micro-CT system. The flat-panel detector consists of a 1248x1248 active matrix of transistors and photodiodes with a pixel pitch of 100μm, and a CsI:TI scintillator. The CsI:TI has a columnar structure with a typical diameter of about 10μm and the thickness of 200μm. The proposed ring artifacts reduction method consists of three parts. Firstly, the reconstructed image (cartesian coordinates image) having ring artifacts is converted into polar coordiantes image where ring artifacts become line artifacts. Secondly, these line artifacts are reduced from the polar coordinates image. If reduction is done acurately, ring artifacts will disappear from reconstructed images. Finally, the resulting corrected image is transformed back into cartesian coordinates image.

A. Transformation into polar coordinates

At first, from the projection data, image is reconstructed where ring artifacts are clearly visible. The resulting image is then transformed into polar coordinates. That is, we transform the coordinate of a point (x,y) in the Cartesian coordinates system into that of the polar coordinates system (r,θ):

$$\begin{cases} x = X_0 + r\cos\theta, \\ y = Y_0 + r\sin\theta, \end{cases} \quad (1)$$

where $O'(X_0,Y_0)$ is chosen to be the origin of the polar coordinates system. In (1), r and θ represent radius and angle respectively. Figure 1 shows the transformation of Cartesian coordinates to polar coordinates system.

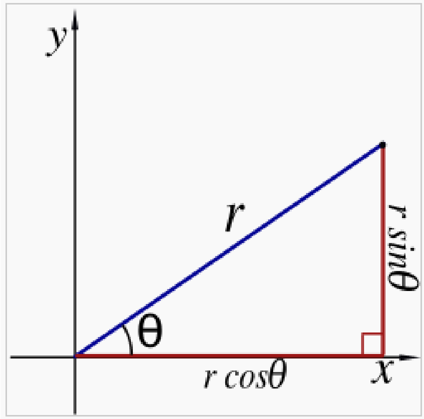
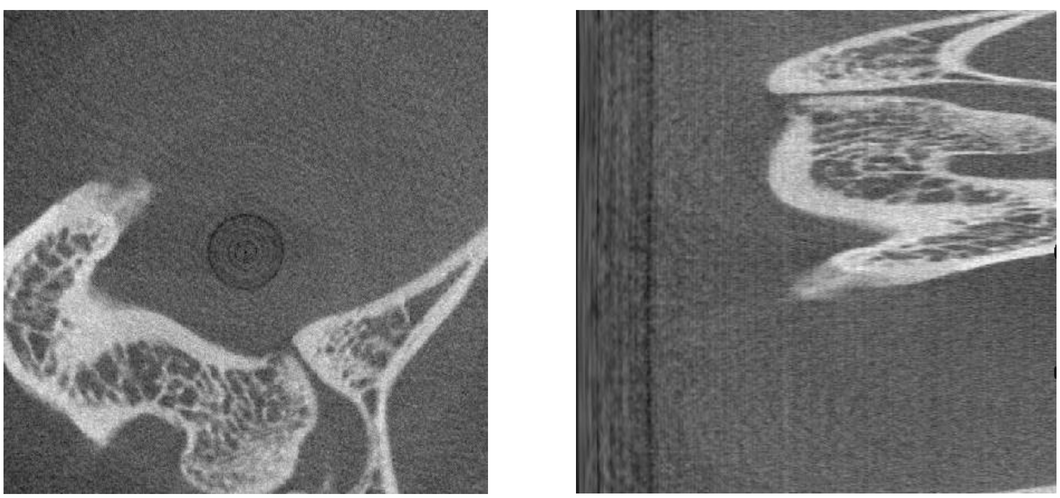


Figure 1. Transformation of Cartesian coordinates to polar coordinates system

For transformation the center of the ring artifacts is chosen as the center of the polar coordinates system. Generally this center is simply the center of the original Cartesian input image. Because of polar transformation, the ring artifacts in Cartesian coordinates become lines in polar coordinates. Fig. 2 shows the result of transformation into polar coordinates from Cartesian coordinates. Bilinear interpolation technique is used for this purpose. Fig. 2 (a) represents the reconstructed image of femur region of a rat where ring artifacts are clearly visible. Fig. 2(b) shows the corresponding polar coordinates image where ring artifacts become clear line artifacts.



(a) **(b)**

Figure 2. Image representation of femur region of a rat; (a) in Cartesian coordinates (b) in polar coordinates.

B. Artifacts correction in polar image

After transformation into polar coordinates, the line artifacts are reduced using the following procedure.

1) A window of fixed size is slid across the polar coordinates image. Assume the size of the polar coordinates image is MxN.
2) For each row of window, the signal variance is computed.
3) Calculate a threshold value for identifying row segments as homogeneous or inhomogeneous.
4) If signal variance is smaller than a specified threshold (calculated in step 3), this row is subtracted by its mean value (normalize) and stacked as a row into a temporary artifact matrix.
5) The final size of the artifact matrix is given by the collection of all rows that meet the homogeneity criterion. That is all the rows whose variances are smaller than the specified threshold value.
6) Then, for each column of artifact matrix, the median value is computed. This results in an artifact template vector.
7) For each window position, the artifact template is stored into a final artifact template row of size 1 × N if the number of rows that meet the homogeneity criterion in that particular window position, is maximal.
8) Finally, the artifact template vector is subtracted from each row of the polar coordinates image.

After performing all the above mentioned steps, line artifacts free image is available. Fig. 3 illustrates the polar coordinates image of femur region of a rat before and after line artifacts correction. Finally line artifacts free polar coordinates image is again transformed back into Cartesian coordinates image where the ring artifacts are reduced significantly.

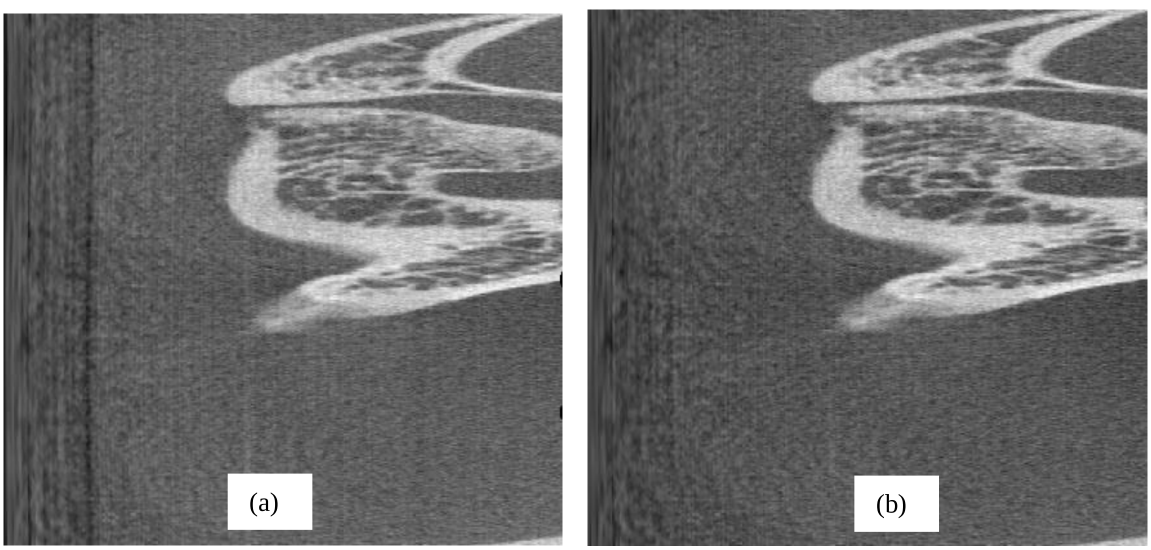


Figure 3. Polar coordinates image of femur region of a rat; a) before and b) after line artifacts correction

The selection of the width of window in step 1 and the threshold value in step 3 are two important factors for removing line artifacts. The purpose of the window is to detect homogeneous row segments. If width of the window is chosen within the range [80-130 pixel] the results are satisfactory. In our experiment, the width of window was chosen as 90 pixels. The selection of threshold value depends on the severity of line artifacts. In this experiment, the threshold value is chosen two times the image noise variance. The noise variance plays an important role for selecting the threshold value in this study. The procedure that is adopted for image noise variance calculation is as follows:

Find the global variance of the whole image of size XxY.

1) Divide the image into sub-blocks of size mxn (m<X & n<Y).
2) Find the local variance of each of the sub-blocks.

3) If the local variance of a particular sub-block is greater than the global variance, we can presume that, that block contains some edge information. We can discard that particular value. Ideally, variance of a sub-image that originally had constant intensity level will reflect true estimate of noise variance
4) Find the average of the retained sub-block variances.
5) Repeat the above procedure (1-5) for sub-blocks of larger size.
6) Once the averages of the sub-block variance are available, find the average of all these averages. This gives us an estimate of the noise variance in the image.

RESULTS AND DISCUSSION

The proposed algorithm is very promising algorithm for reducing ring artifacts from micro-CT images. Results from the experiments using the proposed method for ring artifact correction are presented in Fig. 4 and 5. Ring artifacts correction has been performed on the image data using the proposed method. To test our method we took femur region image of two rats and resolution phantom image. Fig. 4 shows the reconstructed images of the femur region with and without ring artifacts. In Fig. 4(a) and 4(c), the scan data are corrupted by ring artifacts. Ring artifacts are visible in the central region. Fig. 4(b) and 4(d) show the corrected images after removing ring artefacts using proposed method. From these figures, it is clear that ring artifacts are significantly reduced.

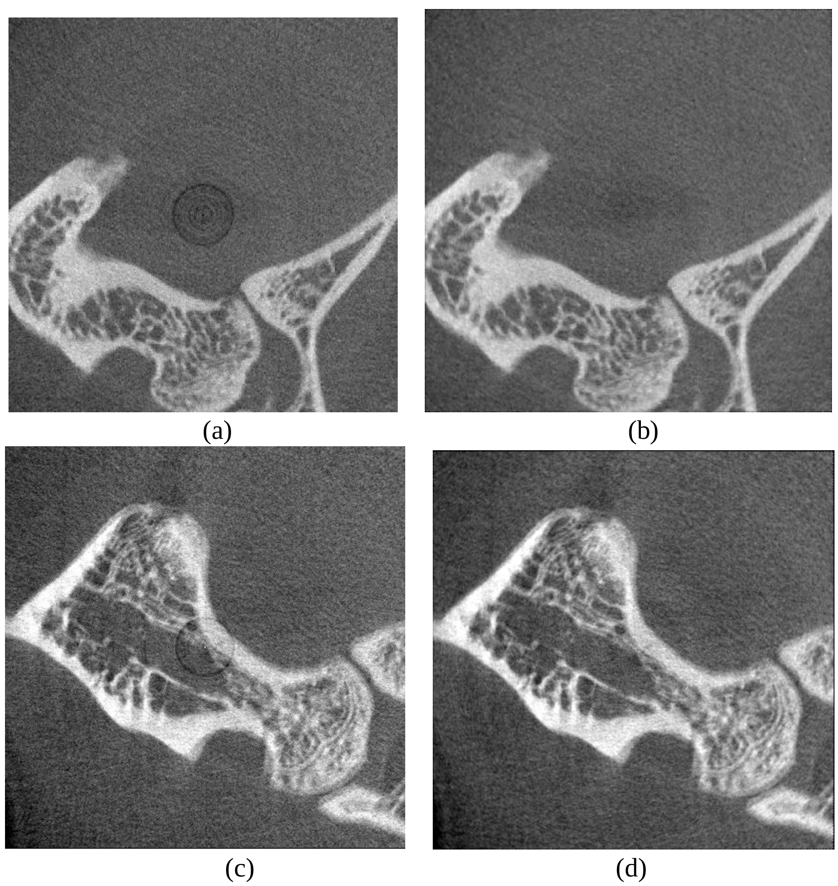
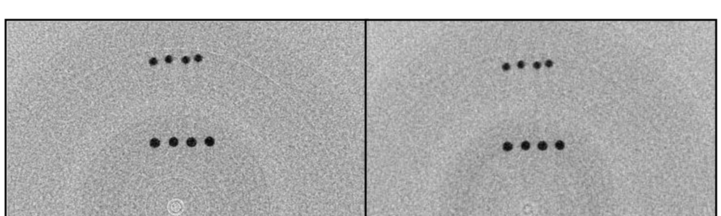


Figure 4. Reconstructed images of the femur region of two rats. (a), (c) Images showing ring artifacts. (b), (d) Corresponding ring artifacts corrected images.



(a) (b)

Figure 5. Reconstructed images of resolution phantom; (a) In iowing ring artifacts. Clear ring artifacts are visible at central region as well as peripheral region orresponding correct image after removing ring artifacts.

The ring artifact correction approach outlined in this paper ed on reconstructed images. If sinogram or projection data are available, it is also possible t ct ring artifacts on sinogram or projection data. But in many cases only reconstructed images are le not the sinogram or projection data. In that case ring artifacts need to be corrected in reconstru age. In the proposed method for reducing ring artifacts from the reconstructed images, the input images need to be transformed into the polar coordinates and after reducing line artifacts from polar coordinates image, the image again transformed back into Cartesian coordinates image. In this case, two-fold interpolation scheme is needed. One is needed while transforming from the Cartesian coordinates image into the polar coordinates image and the other interpolation is needed while transforming back from the polar coordinates into the Cartesian coordinates. So it is needed to use efficient interpolation scheme to preserve the image resolution in all cases. Bilinear interpolation scheme is used in this paper.

CONCLUSION

In this paper an efficient method is introduced to remove ring artifacts from micro-CT images. Unlike the ring artifacts in other types of micro-CTs such as image-intensifier based micro-CT, ring artifacts in a flat-panel detector based micro-CT are hardly removable since the sensitivity of the pixel elements in a flat-panel detector is less uniform than in other types of x-ray detectors. So for a flat-panel detector based micro CT, ring artifact is an unavoidable problem. The proposed method has been evaluated on femur region image of two rats and a resolution phantom image. Experimental results shown that ring artifacts can be removed efficiently without noticeable loss of spatial resolution.

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