Artifacts in Spiral X-ray CT Scanners: Problems and Solutions

Mehran Yazdi, and Luc Beaulieu

Abstract—Artifact is one of the most important factors in degrading the CT image quality and plays an important role in diagnostic accuracy. In this paper, some artifacts typically appear in Spiral CT are introduced. The different factors such as patient, equipment and interpolation algorithm which cause the artifacts are discussed and new developments and image processing algorithms to prevent or reduce them are presented.

Keywords—CT artifacts, Spiral CT, Artifact removal.

I. INTRODUCTION

X-RAY Computed Tomography (CT) has been successfully used as an important medical image modality to reveal the interior organs of human body for many years. Many generations of CT scanners have been designed to improve their geometrical aspect and consequently to reduce the scanning time. In conventional CT scanners, the gantry rotates around stationary patient and all views in a slice are at same table position. It takes around 3-4 seconds between slice scannings. Nowadays, with use of spiral (helical) and cone beam CT [1], the new generations of CT scanners, we are able to save the time by rapid examine of patient during a single breath-hold, as well as to demonstrate a true 3D imaging capability. Spiral CT provides a continuous gantry rotation and a continuous table motion as gantry rotates. So each view is at different table position and no interscan delay is needed. The time between each slice is less than 1 second. In spite of these new technologies, the physical principle of CT scanners is remaining the same and artifacts still persist in spiral CT as in conventional CT. For a x-ray CT, artifacts are the difference between the Hounsfield numbers (or CT numbers or HU) in resulting CT image and the expected attenuation coefficient of objects. Unfortunately, it is not always possible to say if it exists an artifact in CT images because it is difficult to determine the expected values which depend on the viewer (such as physicians) judgment. Here, we focus on the *typical* artifacts which appear in x-ray CT images. Artifacts degrade enormously the CT image quality so that the physicians are not able to give a reliable

diagnostic because the anatomies are hidden or completely distorted.

We can classify the artifacts in four categories:

- **Physics based**: include beam hardening, photon starvation and undersampling artifacts.
- **Patient based**: include metallic and motion artifacts.
- **Scanner based**: artifacts caused by detector sensitivity and mechanical instability.
- **Spiral based**: artifacts arise due to spiral interpolation.

Most artifacts appear as streak effects in CT images (Fig. 1 shows an example of streak artifacts). Metallic objects, beam hardening, photon starvation and object motion can cause the streak artifact. Other important artifacts arise from interpolation aspect of spiral CT. Careful patient positioning and optimum selection of scanning parameters are important factors in avoiding CT artifacts. However, some should be corrected by the scanner software. We discuss common artifacts in CT and give some recent solutions to prevent or reduce them.
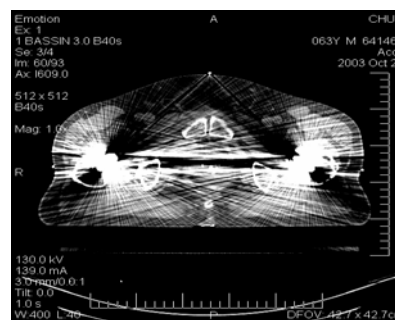

Fig. 1 Example of artifacts produced by scanning a patient with two hip prostheses using a Siemens Somatom scanner, Hotel-Dieu Hospital Center, Quebec, Canada

II. METAL ARTIFACT

A common problem in CT images is streak artifacts caused by the presence of high-attenuation objects in the field of view of scanner device. Metallic implants such as hip prostheses (Fig. 1), surgical clips and dental fillings cause this type of the artifact. The results of scanning a metal object are distinct regions in the projection matrix, i.e. the data exited directly from CT-scanner before CT image reconstruction, with high values. The reconstruction of this matrix using standard CT reconstruction method, i.e. filtered backprojection (FBP), causes the effect of bright and dark streaks in CT images (see

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:1, No:11, 2007

Fig. 1). As a matter of fact, the problem comes from an inaccurate beam hardening correction in FBP [2-3]. Although the new CT scanners are equipped with correction techniques for body organs, the high attenuation objects are still excluded. Metallic artifacts significantly degrade the image quality so that an effective radiation treatment planning cannot be applied.

Different techniques for metallic artifact reduction (MAR) have been proposed [4-6]. The most efficient methods work on projection matrix. Two different methods have been introduced. In iterative reconstruction methods, the projection data associated with metal objects in projection matrix are disregarded and reconstruction is applied only for non-corrupted data [7-10]. Although these algorithms are reliable for incomplete/noisy projection data, they must deal with convergence problems and they are computationally expensive for clinical CT scanners (even with their fast implementation [11]).

In projection-interpolation based methods [12-16], the projection data corresponding to rays through the metal objects are considered as missing data. Kalender et al. [12-13] identified manually the missing projections and replaced them by interpolation of non-missing neighbor projections. Rajgopal et al. [14] used a linear prediction method to replace the missing projections. In other work [15], a polynomial interpolation technique is used to bridge the missing projections. A wavelet multiresolution analysis of projection data is also proposed to detect the missing data and interpolate them [16].
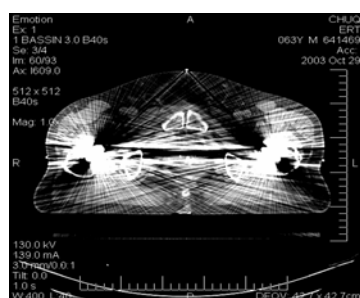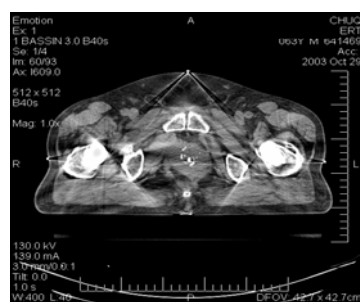
centred by the missing projection. The weights are modeled only based on the distance. Although they exploit the contribution of not-affected projections in all directions to determine the replacement values, they do not preserve the continuity of the structure of these projections. Furthermore, because there is no continuity between resulting replacement values, the risk of noise production is also high. In my previous work [18], an optimization scheme is proposed by exploiting both the distance and the value of not affected projections to determine the interpolation values and by using still an interpolation scheme to preserve the continuity of replacement values. This new scheme computed more effectively the interpolation values based on the structure of nearest not affected projections and resulted an excellent performance in the case of hip prosthesis. Fig. 2 shows the result of applying this proposed method on two hip prostheses in Fig. 1.

III. PHOTON STARVATION ARTIFACT

Photon starvation can cause streak artifacts, especially near to the heart, hip and shoulder where the patient's tissue volume increases. This can be particularly seen in patients with mass body. Artifacts arise because some parts of individual projection can be very noisy due to insufficient photons passing through widest part of patient. Fig. 3 (a) shows these projects in the projection matrix for a patient. When these projects are reconstructed by standard algorithm of scanner, the noise is magnified, resulting in streaks in the direction of widest part (Fig. 3 (b)).

(a)

(b)

Fig. 2 Result of applying the method proposed in [18] for reduction of metallic artifacts; a) original CT image, b) modified CT image
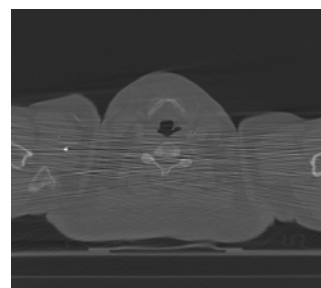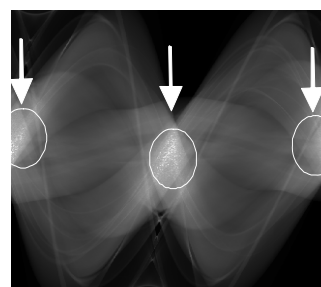

(a)

(b)

Fig. 3 Example of photon starvation artifact; a) matrix of projections, the circles show the noisy regions, b) resulting CT image (provided by Siemens Somatom scanner, Hotel-Dieu Hospital Center, Quebec, Canada)

Recently, Mahenken et al. [17] used another strategy for computing the interpolation value by the sum of weighted nearest not-affected projection values within a window

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
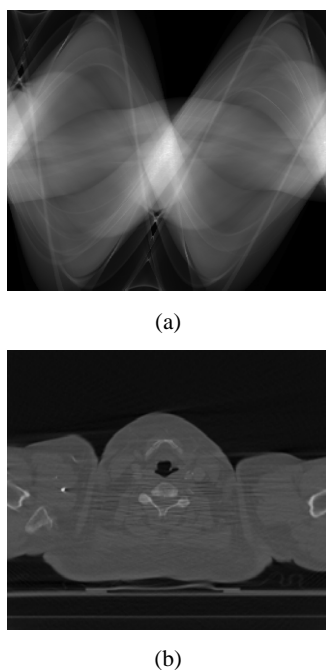Vol:1, No:11, 2007

(a)

(b)

Fig. 4 Result of photon starvation removal by applying an optimal adaptive filtering; a) modified matrix of projections, b) resulting modified CT image
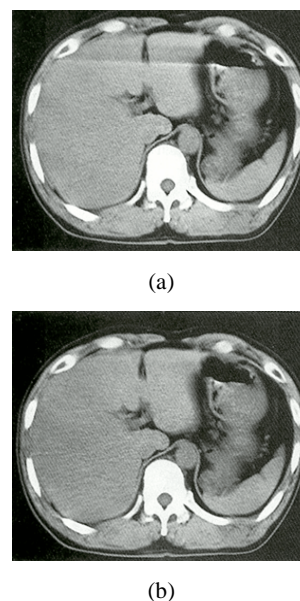

(a)

(b)

Fig. 5 Example of patient motion artifact; a) original image with artifact, b) modified image with removal artifact (images are provided by St George's Hospital, Tooting, London)

Some scanners use a mA modulation allowing an increase of photon flux (by increasing current (mA) through the scanner tube) through widest parts without changing the photon flux through narrower parts. In this way, the number of photons received by all detectors will be balanced. We can also use an adaptive filtration of the projections to reduce this effect [19]. In this approach, the areas on projection matrix with high values are smoothed, resulting in reducing the noise. An extension of this is multi-dimensional adaptive filtration, where further steps are taken to reduce noise levels in certain projections [20]. The success of this approach depends on choosing the best filter parameters and detecting correctly the areas where the filter should apply. Fig. 4 shows the result of applying an adaptive filter experimentally optimized for the patient in Fig. 3. As we can see, the streak artifacts are mostly removed.

IV. MOTION ARTIFACT

Patient movement during CT scanning results in image artifacts, which appear as streaks or blurring effects across an image (see Fig. 5 (a) as an example). The movement can be voluntary, such as the movement of the chest during inspiration and expiration, or involuntary such as cardiac motion, both cause motion artifacts. Severely injured patients or children frequently move during scanning, causing motion artifacts.

In spiral CT scanners, the scan is usually short enough for patients to hold their breath, thus removing the possibility of breathing artifact. Besides, some techniques can be used during scanning to reduce the effect of motion artifacts [21]. However, the cardiac motion is still a problem. Some new CT scanners are equipped with the technique of ECG gating which allows synchronizing the data acquisition with the rhythmic beating of the heart. The key elements of the new technology include acquiring an image of the heart by triggering an image acquisition scan starting at the point of the cardiac cycle having minimized motion.

Some correction algorithms are also proposed for motion artifact removal. Crawford et al. developed a pixel-specific filtered backprojection algorithm for motion artifact reduction [22]. In their algorithm, in-plane motion is corrected by pixel-specific reconstruction in the coordinate system associated with the in-plane motion.

We can also overscan the heart area and average the repeated projections to remove the effect of cardiac motion. Fig. 5 (b) shows the result of applying this approach to remove motion artifacts.

V. SPIRAL ARTIFACT

In general the same artifacts are produced in spiral and conventional scanning. Meanwhile, because the spiral scanning requires an interpolation process to recover the consistent projections of individual slices, additional artifacts may be produced. Appearance and severity of spiral artifacts depend on scanning pitch and the type of interpolation algorithm. In single CT spiral scanner, the pitch is the table movement per tube rotation/slice collimation. For a typical 1 second rotation scanner a pitch of 2 means the table traveled 10 mm with a 5 mm slice width or collimation. In multi-slice CT spiral scanners, the definition is table movement per rotation/single slice collimation. With a 1 sec scanner there is 1 rotation per second. So if the table travels 4 mm in a second and a 1 mm collimator is used then the pitch would be 4. Fig. 6 shows a spiral scanning and the pitch for this scanning. If pitch is increased while holding kVp, mA, and beam collimation constant, then the table speed increases, mAs

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:1, No:11, 2007

decreases, patient dose decreases, and either the effective slice width increases or the image noise increases. So for reducing the artifacts due to spiral rotation, we should decrease pitch. Fig. 7 shows the effect of reducing pitch for a multi-slice spiral scanner [23].
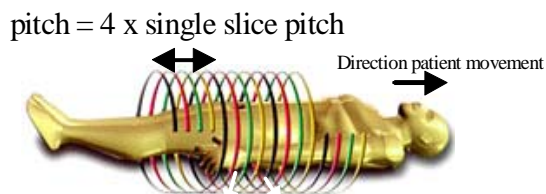

Fig. 6 Multi-slice spiral scanning

Because during the gantry rotation, the table is moving, we need to use an interpolation to average data either side of the reconstruction position to estimate projection data at that point. There are two algorithms: 360 and 180 degree algorithms. In spiral scanning the individual views that represents the X-ray absorption describes a spiral movement over the patient (see Fig. 6). This means that for image reconstruction only one view is in the same plane for being reconstructed plane. All the other views are before and after
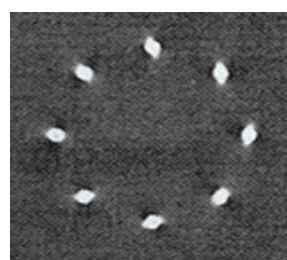
(a)

(b)
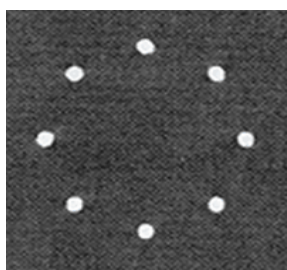
(c)

Fig. 7 The effect of decreasing pitch on reducing image artifacts; a) pitch=4.5, b) pitch=3.5, c) pitch=2.5 [23]

the reconstruction plane. Thus, the views required for a pure cylindrical data set and also required for an appropriate image reconstruction are calculated through interpolation of views with the same view angle. The weighting factor of the individual views within this interpolation is computed by distance of this view to the reconstruction plane and has a linear relation. This interpolation technique is called 360-degree interpolation. 180 degree interpolator makes use of the fact that opposite views are equivalent. So, a spiral data set interpolation is applied over 180 degrees of data on either sides of the reconstruction plane. This data set is also called complementary data (see Fig. 8). Again the weighting factor is computed by distance of the view to the reconstruction plane and has a linear relation. This interpolation technique is called 180-degree interpolation. Fig. 8 shows these interpolation techniques.
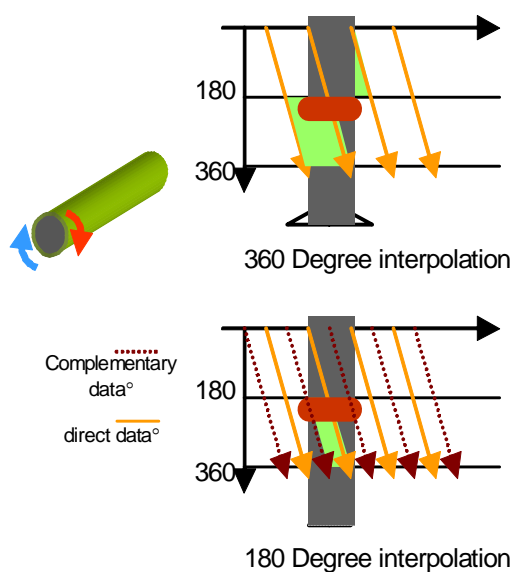

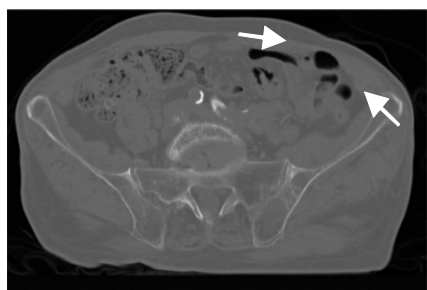Fig. 8 360 and 180 degree interpolation algorithms

Since the 360 degree interpolation uses two views, each reconstructed image is representing a width slice. The 180 degree interpolation does not suffer from this enlarged slice width since it uses only one view. So the artifacts due to interpolation are less effective. Fig. 9 shows the result of reconstructing a CT image using two interpolation techniques. As we can see, the 180 degree interpolation produces fewer artifacts. In general practice, the 180 degree interpolation algorithm is used to reconstruct CT images.

VI. CONCLUSION

Many sources can be the origin of CT artifacts. Artifacts degrade the CT image quality and consequently reduce diagnostic quality. Most artifacts can be prevented by using new designs in scanner technology, by careful positioning of patients during scanning, and by optimum selecting of scanner parameters (pitch, filter kind, delivered energy). Some others can be reduced by addressing the problem in software developments.

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:1, No:11, 2007

(a)

(b)

Fig. 9 The effect of interpolation algorithms on artifacts produced in reconstructed CT images; a) reconstructed CT image with 360 degrees interpolation algorithm, b) reconstructed CT image with 180 degrees interpolation algorithm. Arrows show the observed artifacts due to 360 interpolations which are reduced in 180 interpolation (images are provided by Siemens Somatom scanner, Hotel-Dieu Hospital Center, Quebec, Canada)

REFERENCES

[1] Kalender WA, "Computed tomography: fundamentals, system technology, image quality, and applications" Wiley, John & Sons, 1999.
[2] Joseph PM, Ruth C. A method for simultaneous correction of spectrum hardening artifacts in CT images containing both bone and iodine. Med Phys. 1997; 24: 1629-1634.
[3] Herman GT. Correction for beam hardening in computed tomography. Phys Med Biol. 1979;24:81-106.
[4] Robertson DD, Weiss PJ, Fishman EK, *et al.* Evaluation of CT techniques for reducing artifacts in the presence of metallic orthopedic implants. Jour. Comput. Assist. Tomogr., 1988; 12(2): 236-241.
[5] Ebraheim NA, Coombs R, Rusin JJ, *et al.* Reduction of postoperative CT artefacts of pelvic fractures by use of titanium implants. Orthopedics, 1990; 13: 1357-1358.
[6] Ling CC, Schell MC, Working KR, *et al.* CT-assisted assessment of bladder and rectum dose in gynecological implants. Int. Jour. Radiat. Oncol. Biol. Phys., 1987; 13: 1577-1582.
[7] Wang G, Snyder DL, O'Sullivan JA, *et al.* Iterative deblurring for CT metal artifact reduction. IEEE Transactions in Medical Imaging, 1996; 15(5): 657-664.
[8] Robertson DD, Yuan J, Wang G, *et al.* Total hip prosthesis metal-artifact suppression using iterative deblurring reconstruction. Journal of Comput. Assist. Tomogr., 1997; 21(2): 293-298.
[9] Nuyts J, De Man B, Dupont P, *et al.* Iterative reconstruction for helical CT: a simulation study. Phys. Med. Biol., 1998; 43(4): 729-737.
[10] Wang G, Vannier MW, Cheng PC, *et al.* Iterative x-ray cone-beam tomography for metal artifact reduction and local region reconstruction. Microscopy and Microanalysis, 1999; 5(1): 58-65.
[11] Toft P. A very fast implementation of 2D iterative reconstruction algorithms. IEEE proceeding of Medical Imaging Conference, 1996; 3: 1742-1746.
[12] Kalender WA, Hebel R, Ebersberger JA. Reduction of CT artifacts caused by metallic implants. Radiology, 1987; 164(2): 576-577.
[13] Klotz E, Kalender WA, *et al.* Algorithms for reduction of CT artifacts caused by metallic implants. SPIE Medical Imaging IV, 1990; 1234: 642-650.
[14] Srinivasa N, Ramakrishnan KR, Rajgopal K. Image reconstruction from incomplete projection. Journal of Medical and Life Sciences Engg, 1997; 14: 1-19.
[15] Lewitt RM, Bates RHT. Image reconstruction from projections: III: projection completion methods. Optik, 1978; 50(3): 189-204.
[16] Zhao S, Robertson DD, Wang G, *et al.* X-ray CT metal artifact reduction using wavelets: an application for imaging total hip prostheses. IEEE Transactions on Medical Imaging, 2000; 19(12): 1238-1247.
[17] Mahnken AH *et al.* A new algorithm for metal artifact reduction in computed tomography: in vitro and in vivo evaluation after total hip replacement. Invest. Radiol., 2003 Dec; 38 (12): 769-775.
[18] Yazdi M, Gingras L, Beaulieu L. An adaptive approach of metal artifact reduction in helical CT for radiation therapy treatment planning: experimental and clinical studies. Int. Jour. Radiat. Oncol. Biol. Phys., under publish.
[19] Hsieh J, Adaptive streak artifact reduction in computed tomography resulting from excessive x-ray photon noise. Medical Physics 1998; 25, (11): 2139-2147.
[20] Kachelriess M, Watzke O, Kalender WA. Generalized multi-dimensional adaptive filtering for conventional and spiral single-slice, multi-slice, and cone-beam CT. Med Phys 2001; 28(4): 475-90.
[21] Goerres GW, Burger C, Kamel E et al. Respiration-induced attenuation artifact at PET / CT: technical considerations. Radiology 2003; 226: 906-910.
[22] C. R. Crawford, K. F. King, C. J. Ritchie, and J. D. Godwin. Respiratory compensation in projection imaging using a magnification and displacement model. *IEEE Trans. on Med. Imag.*, 1996; 15:327-332.
[23] Taguchi K, Aradate H, Algorithm for image reconstruction in multi-slice helical CT, Medical Physics, 1998; 25(4):550-561.