Artifacts suppression in optical CT for gel dosimeters by iterative reconstruction

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Abstract. Optical CT has been considered as an important and promising readout method for 3D gel dosimetry. However, tomographic image qualities are often corrupted by artifacts such as streaks and rings, which are induced by projection discontinuities and magnified by FBP reconstruction. These artifacts will surely deteriorate the accuracy and precision of dose measurement. In this paper, we performed a preliminary study on our in-house optical CT scanner using an iterative algorithm instead of the commonly used FBP for image reconstruction. Comparative analysis of the results validates the proposed method in artifacts suppression and image quality improvement when the convergent process is properly controlled.

1. Introduction
Gel dosimeters such as PAGs and FXGs have potential advantages over conventional dosimeters especially for high resolution and tissue equivalent 3D dosimetry, which serves suitable for 3D dose verification in radiation therapy quality control and assurance (QC&A) [1-4]. After exposure to ionizing radiation, the optical densities (ODs) of gel dosimeters change quantitatively to absorbed doses, and thus 3D dose information is stored in the form of OD distribution, which can be read out by optical CT. Several prototype and two commercial optical CT scanners have been proposed [5]. Key components of a typical optical CT scanner consist of a visible source, a water tank with matching liquid, a sample gel dosimeter and a detector. Since incident light rays pass through several interfaces before finally reaching the detector, interface imperfections such as surface damages and stains will introduce discontinuities into projection signals. Unfortunately, these errors will be manifested in the form of image artifacts such as streaks and rings after filtered back-projection (FBP) reconstruction, which will magnify discontinuities in the projection filtering [6]. In order to suppress streak and ring artifacts in optical CT, a lot of work has been done in projection preprocessing. To achieve the same goal, we utilized an iterative reconstruction algorithm instead of the classic FBP in this paper.

2. Method
2.1. Optical CT scanner & polymer gel dosimeter
We have built an in-house prototype optical CT scanner showed in figure 1, with a Hg light as the source and a CCD camera as the detector. Incident light rays are monochromized by a 580nm filter, and are collimated by an aperture [7]. The sample container is suspended and rotated from its top. 400 frames of projection signals were obtained at equal intervals over 360 degrees, and each frame
consisted of 50 rows. The source-to-iso distance is so large as 900mm that the scanning geometry can be approximated to the parallel beam geometry.

A polymer gel dosimeter known as MAGIC was in-house made in strict accordance with [8] and used in this study. The MAGIC sample was held in a PMMA container, and a square field at the center was irradiated uniformly from the top by a medical linear acceleration for radiation therapy. Figure 2 shows one frame of the raw projections of the irradiated sample with imperfection of two visible seams on the container.

2.2. Projection preprocessing

The sample gel dosimeter was scanned twice in this study: before the irradiation ($P_{\text{before}}$) and after the irradiation ($P_{\text{after}}$). Background noise were also obtained in the process. The logarithmic projections ($g$) used for reconstruction were calculated by the following equation (1) [9]:

$$g_\theta = -\ln \left( \frac{P_{\text{after}} - \text{Noise}_{\text{after}}}{P_{\text{before}} - \text{Noise}_{\text{before}}} \right)$$

Since the cylindrical gel container interfaces reflected and refracted the incident rays, and the ray path deflection got larger near the edges of the container, the bilateral outer parts of the projections were discarded to eliminate edge reflection and refraction related errors.

2.3. Simultaneous iterative reconstruction technique (SIRT) with total variance (TV) minimization

Several iterative CT reconstruction algorithms such as ART, SART, SIRT, ML-EM have been under research for long and applied in certain areas. Compared to the classic FBP algorithm that is analytic in nature, iterative algorithms can be more exact in physical modelling and capable of incorporating prior-knowledge in reconstruction process.

In this study, we used SIRT for optical CT reconstruction, which stands out for great stability, noise suppression and convergence. The algorithm can be expressed as equation 2 [10]:
\[
\begin{align*}
  f^{(k+1)} &= f^{(k)} + \lambda R^T (g - Rf^{(k)}) \\
  \text{s.t. } Rf^{(*)} &= g
\end{align*}
\]  

(2)

where \( R \) is the system matrix, \( f \) is the target tomographic image to be reconstructed, \( g \) is the logarithmic projections, and \( \lambda \) is the relaxation factor.

Besides, total variance (TV, defined in equation 3) [11] minimization was also added into the iteration. TV minimization is a piece-wise based optimization rule, and has shown its high performance in edge-preservation and noise reduction. It’s introduced here for further artifact reduction.

\[
TV(f) = \int \int \left( \frac{\partial f}{\partial x} \right)^2 + \left( \frac{\partial f}{\partial y} \right)^2 \, dx \, dy \approx \sum_{i,j} \sqrt{(\Delta f_i)^2 + (\Delta f_j)^2}
\]

(3)

where \((i, j)\) is the pixel location index of the tomographic image.

3. Results & discussion

For comparison, tomographic images were reconstructed respectively by FBP and SIRT (TV). The projection preprocessing and reconstruction software was in-house developed in C++ language on the Visual Studio 2012\textsuperscript{TM} platform. All images were of 208*208 pixels, and each pixel was 0.18*0.18 mm\(^2\). For illustration, figure 3 shows the middle plane (Slice 25\textsuperscript{th}) results by FBP (a) and SIRT (TV) at different iteration times (10, 30, 50, 100, 200) with zero initials.

Figure 3. Reconstruction results of the middle plane by FBP and SIRT (TV)
In figure 3(a), streaks and rings are easy to identify as well as high noise, which are probably related to the imperfect surfaces of the water tank and sample container. Figure 3(b)–(f) shows the convergent process of SIRT (TV). It’s found that the image qualities didn’t get improved all the way as the iteration continued. At the start, low frequent information of the image, such as the shape of the irradiated area, was reconstructed. Then, the high frequent details, say the edges, got restored, while noise and artifacts also became visible and began to deteriorate at the same time (this could be attributed to the poor quality projection data which the iteration algorithm used as the convergent target). Therefore, the iteration process should not go too far, in case of serious artifacts as well as long calculation time.

Figure 3(c) was selected as the optimal SIRT (TV) result, and its middle profile was drawn in figure 3 as well as that of figure 3(a). From figure 4, we can clearly see that the large vibration, which represents sharp artifacts, has been well suppressed as we desire.

![Figure 4. Profiles of reconstructed images by different algorithms](image)

4. Conclusion
We have performed a preliminary study on artifact suppression by using iterative algorithm instead of the widely used FBP for optical CT reconstruction on an in-house optical CT scanner with MAGIC gel dosimeters. The results by SIRT (TV) showed much fewer artifacts and less noise than that of FBP, when the iteration time was properly selected. The profile comparison demonstrated the effectiveness and efficiency of the iterative reconstruction algorithm in optical CT image quality improvement with streak and ring artifact suppression.

5. Acknowledgements
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6. References
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