Computational simulations of the influence of background noise removal in optical-CT imaging of gel dosimeters

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Abstract. Background noise removal is an easy way to diminish the impact of imperfect signals in the projection blank regions in optical CT imaging of gel dosimeters. The influence of this approach to reconstruction accuracy and noise behaviour is assessed by computational simulations using synthetic phantoms. The results show that an offset is induced in the reconstructed phantom region by background noise removal, but the amplitude of the offset is negligible. Also, no apparent noise or artefact patterns are noticeable. We can conclude that the background noise removal method doesn’t impact the reconstruction accuracy of filtered backprojection reconstruction algorithm for optical CT imaging.

1. Introduction

Gel dosimetry has received interest for its outstanding volumetric dose distribution measurement performance [1]. After irradiation, radiation-sensitive gel dosimeters can be read out by either MRI or optical CT [2-4]. Optical CT, utilizing the optical density changes induced by absorbed doses, has been proposed as an alternative readout method to MRI. Several optical CT configurations have been proposed [5].

In a typical optical CT scanning, light emitted from the light source is attenuated by the gel phantom, and forms traverse projections captured by the detector. After acquiring projections over 360 degrees, the tomographic images of the optical densities (ODs) of the gel phantom can be reconstructed by either filtered backprojection or iterative reconstruction algorithms. Absolute dose maps can be derived from the OD distribution by the OD-to-dose calibration. A typical gel phantom projection can be separated in two regions: the central data region containing gel phantom attenuation information, and the peripheral background region, which also contains noise and possible artefacts originating from impurities, such as scratches and stains). It’s intuitive to set the background region at zero, which is called background noise removal. Although this approach works well for iterative reconstruction algorithms as shown in [6], for the classic filtered backprojection algorithm, currently the standard reconstruction method for optical CT, background noise removal may induce errors and impair the reconstruction accuracy, because of the filtering operation.

In this study, we investigate the influence of background noise removal to reconstruction accuracy of optical CT imaging of gel dosimeters.
2. Methods and Materials

2.1. Noise Modelling
As in [7], the system noise is assumed as stochastic white noise, which corresponds with the combined effect of thermal noise and shot noise. We derived the noise properties from measurements on our cone-beam optical CT scanner [8]. The standard deviation in four selected ROIs in background region was used as the estimate of the noise. The noise standard deviation is 1.5% normalized to the maximal signal in the CCD camera.

2.2. Simulation
Additive stochastic white noise was generated and added to simulated traverse projections as detailed in the following subsection. To assess the influence of the background noise removal method, two simulation scenarios are set with a cylindrical phantom and an elliptical phantom respectively.

2.3. Synthetic Phantoms

2.3.1. Cylindrical Phantom
Since gel dosimeters are usually prepared in a cylindrical cast, a cylindrical phantom is commonly used for gel dosimetry. A synthetic cylindrical phantom is considered to mimic a square-field dose distribution from a 6-MV linac with 100 cm SSD [7], as in Figure 1(a). The optical density (irradiation) field is 2 cm wide and 2 cm offset from the centre to avoid any bias created by cylindrical symmetry. The phantom is 10 cm in diameter, and 10 cm in height. The central axial optical density distribution is show in Figure 1(a). We used the specifications of our optical CT scanner for simulation, while stochastic noise was added to the projection as shown in Figure 1(b)-(c). To nullify the background noise, a threshold was applied to segment the background in the projection image (Figure 1(d)-1(e)).

![Figure 1](image1.png)

Figure 1. (a) Central axial slice of the cylindrical phantom. Projection images at 0 ° (b) and 90 ° (c), and the corresponding central row profiles shown in (d) and (e) with background noise removed.

2.3.2. Elliptical Phantom
To study the effect of background noise removal to non-cylindrical gel phantom, an elliptical phantom is used here, of which the major-axis is 10 cm and minor-axis 5 cm. The optical density (irradiation) field is 1 cm wide, and 2 cm offset from the centre in y-direction. The central axial optical density...
distribution is shown in Figure 2(a). The same simulation parameters as 2.3.1 are used. Projections with noise are shown in Figure 2(b)-(c), and the central row profiles in Figure 3(d)-(e) to show the noise removal effect.

![Figure 2](image1)

Figure 2. (a) Central axial slice of the elliptical phantom. The projections at 0° (b) and 90° (c), and the central row profiles are shown in (d) and (e), with the background noise removal effect plotted.

3. Results and Discussion

3.1. Cylindrical Phantom

Tomographic images of the cylindrical phantom were reconstructed via the cone-beam filtered backprojection algorithm (FDK) with a Hann filter for its outstanding noise performance (shown in Figure 3(a)-(b)). In the difference map (Figure 3(c)), we can observe a flat offset, but the amplitude is very small. As shown in Figure 3(d)-(e), the influence of background noise removal is no more than 0.3% normalized to the ΔOD in the square field.

3.2. Elliptical Phantom

The reconstruction results of the elliptical phantom were shown in Figure 4, from which we can draw the same conclusions as above.

Note that, except for the flat offset in Figure 3(d)-(e) and Figure 4(d)-(e), we didn’t see any obvious artefact pattern caused by noise cutoff. Also, we calculated the Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) inside and outside the OD field in both phantoms, and we find that the background noise removal method will increase the SNR in reconstructed images, but the improvement is also very small.
Figure 3. Central axial slices of the cylindrical phantom projections (a) without and (b) with background noise removal. The difference map between (a) and (b) is shown in (c). The horizontal and vertical profiles are plotted in (d) and (e), where the pixel value is normalized by the mean value of the $\Delta OD$ in the square field.

Figure 4. Central slice reconstructed results of the elliptical phantom projections (a) with blank region noise and (b) with blank region noise cutoff. The difference map between (a) and (b) is shown in (c). The horizontal and vertical profiles are plotted in (d) and (e) with normalized pixel values.

4. Conclusions
In both cylindrical and elliptical scenarios, a flat offset is observed, but the amplitude is so small that the effect can be considered negligible. Meanwhile, no apparent noise or artefact pattern is noticeable. We can conclude that impact of the background noise removal to the reconstruction accuracy of filtered backprojection algorithm is negligible in the interested phantom and dose regions. This also implies that, as an efficient trick to accelerate the reconstruction process, cropping the projections to a smaller size won't induce any noticeable loss to accuracy. Besides, the method described in this study
can be easily applied to investigate the influence of artefacts removal outside the sample region, and we believe that similar conclusions could be drawn.

5. Acknowledgement
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6. References
[1] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[2] De Deene Y et al 2002 Phys. Med. Biol. 47 2459
[3] De Deene Y and Baldock C 2002 Phys. Med. Biol. 47 3117-41
[4] De Deene Y et al 2002 Phys. Med. Biol. 47 3441-63
[5] Doran S J 2009 J. Phys.: Conf. Ser. 164 012020
[6] Yi D et al 2015 J. Phys.: Conf. Ser. 573 012063
[7] De Deene Y 2015 J. Phys.: Conf. Ser. 573 012076
[8] De Deene Y 2015 J. Phys.: Conf. Ser. 573 012058