Multiple slot array collimator to minimize stray light in optical cone beam CT

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Abstract. Acceptance of stray light in transmission images is a general imaging problem. A commercial optical cone beam CT scanner, Vista10 was modified to reduce stray light. Further stray light reduction was accomplished by placing vertical slot aperture arrays between the object and the diffusive light source. Comparisons of single and seven aperture arrays demonstrated that transmissions equivalent to scatter free conditions can be achieved with a multiple array collimator. Results for uniform liquids and finger gel phantoms demonstrate that small objects in a bright background are a more stringent test of stray light rejection.

1. Introduction
Optical cone beam CT uses one of the simplest data acquisition geometries. Transmission images through the radiation sensitive dosimeter material are recorded as the object is rotated within an aquarium containing a reference liquid with a similar refractive index [1]. The light source consists of a planer diffuser backlit by light emitting diodes. The geometry is inversely analogous to x-ray cone beam CT with the diffuser sheet replacing the flat-panel CCD array detector and the image forming aperture of a camera substituting for the point source. Improving scatter corrections for x-ray cone beam CT is an active area of academic and commercial research [2].

Investigations of stray light in the Modus optical cone beam CT scanner (Vista10, Modus Medical London, Canada), suggest that increasing the distance of the diffuser from the rotation axis, removing the bandpass filter at the camera lens and using a compensating light distribution can reduce the amount of stray light in transmission measurements. Aperture arrays are also efficient for measuring residual stray light that can be subtracted from raw transmission data. One particularly effective and simple approach is to employ such an array with equally spaced open and blocked areas. Multiple images are recorded and "stitched" together to form open and shadow images. The difference image represents the primary light for input to the CT image reconstruction algorithm [3]. The initial work involved one slot array at the input face of the aquarium. In this study, the implementation of multiple slot arrays is compared to assess performance of the stray light reduction strategy.

2. Methods
The Vista10 scanner was modified by removing the uniform diffuse light source and substituting a larger diffuser at 100 cm from the rotation axis, as shown in Figure 1. A filtered line source was constructed from three LED’s (Luxeon III) mounted vertically to a strip heat sink, each weakly...
collimated with a lens and spectrally filtered with a 10 nm bandpass filter centred at 590 nm. The LED’s backlight the diffuser sheet. Slot arrays were manually cut from radiographic film. The first aperture array had slots widths and separations of 1.0 cm. Subsequent apertures were scaled according to system magnification and adjusted to have a ratio of 60% open to 40% blocked areas. Three images were acquired with the first slot array, centred and translated ± 7 mm. The central 70% of the open and shadow areas were stitched together to form open and shadow images. A difference image is a close approximation to the primary image required for CT reconstruction. For the multi-array sets, the additional arrays were positioned according to the divergence of the modified scanner. Reference images were obtained by collapsing the optical cone beam scanner to a fan beam geometry by placing horizontal slots at the aquarium and near the diffuser plate.

Figure 1. Top view schematic of modified Vista10 optical cone beam CT scanner. From right to left: LED array, diffuser plate, image forming rays, vertical slot arrays, aquarium, sample, CCD camera.

Test solutions were made by adding Intralipid and trace amount of carbon black nanoparticles suspended in micelles of Triton X-100 to water. The Intralipid provided a linear attenuation coefficient for scatter of approximately 0.1 cm\(^{-1}\). This simulated twice the amount of scatter as in a 4% gelatin hydrogel. The carbon black concentration was adjusted to provide varying degrees of absorption. Hydrogen peroxide was added to eliminate microbial growth and extent shelf life of the solutions [4]. The reference solution was water. The transmission values of the solutions were independently measured in 10 cm quartz cuvettes with a He-Ne laser at 594 nm. In a similar manner, carbon black nanoparticle micelles gels were prepared as stable hydrogel finger phantoms with diameters of 2.54, 1.27 and 0.48 cm [5]. The finger phantoms represent a very difficult geometry for transmission imaging since the object is surrounded by a bright background. For these finger phantom experiments the reference sample was a uniform gel (without "fingers") from the same batch.

3. Results
The solution transmission values were chosen to extend to the lower limits that still provided accurate results. Figure 2, shows transmission images for the darkest solution recorded with zero and 7 slot arrays. The images have been adjusted to the same window and level for comparison. Note the cylinder wall is clearly seen once stray light is reduced. The transmission measurements are summarized in Table I.
Figure 2. Transmission images of carbon black micelle solution with intralipid, same window and level: top image, open geometry (zero slot arrays), bottom image (7 slot arrays). Note the cylinder wall as a shadow line in slot opening (left bottom) and as a bright line in slot shadow (right bottom) compared to open image where cylinder walls are not visible due to stray light.

|                  | Solution 1 | Solution 2 | Solution 3 | Solution 4 |
|------------------|------------|------------|------------|------------|
| Laser (594 nm)   | 0.081      | 0.236      | 0.430      | 0.499      |
| Open             | 0.075      | 0.233      | 0.422      | 0.487      |
| Single slot array| 0.079      | 0.236      | 0.428      | 0.496      |
| Seven slot arrays| 0.081      | 0.238      | 0.430      | 0.497      |

Table I. Linear attenuation coefficients (cm$^{-1}$) of carbon black nanoparticle micelle solutions with Intralipid scattering. Stray light was minimized using vertical slot arrays.
The linear attenuation coefficients measured for the fan beam (single horizontal slot, 1 cm height), open field, single slot array and seven slot array collimators are shown in table II. The 2.54 cm diameter finger demonstrated the expected trend; as stray light is reduced in the system, measurements converge to the fan beam result. Similar trends are seen for the smaller 1.27 and 0.48 cm fingers but the results are noisier since the change in transmission is proportionally lower.

| Slot (reference)       | 2.54   | 1.27   | 0.48   |
|------------------------|--------|--------|--------|
| Finger diameter (cm)   |        |        |        |
| Open                   | 0.287 / 0.288 | 0.271 / 0.276 | 0.324 / 0.326 |
| Single slot array      | 0.291 / 0.298 | 0.279 / 0.281 | 0.331 / 0.325 |
| Seven slot array       | 0.300 / 0.309 | 0.277 / 0.283 | 0.357 / 0.346 |

Table II. Linear attenuation coefficients (cm\(^{-1}\)) of carbon black nanoparticle micelle hydrogel "finger" phantom. Paired data correspond to independent measurements before and after a 180 degree rotation of the finger phantom.

4. Summary
Stray light in optical cone beam CT can be reduced by incorporating several innovations: extending the distance from the diffuser to the object, removing the bandpass filter at the camera lens (reduces glare), customizing the light source distribution and introducing collimating aperture arrays. Fan beam geometry provides an internally consistent geometry for comparisons with cone beam stray light reduction strategies. Finally multiple slot aperture arrays can further reduce stray light and increase the quantitative dynamic range of the transmission images to yield more accurate reconstructions.

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References
[1] J. G. Wolodzko, C, Marsden and A. Appleby, 1999 CCD imaging for optical tomography of gel radiation dosimeters, Med Phys 26: 2508-2513,
[2] Zhu L, Xie Y, Wang J and Xing L, 2009 Scatter correction for cone beam CT in radiation therapy Med Phys 36 2258-68
[3] Granton P, Battista J and Jordan K, Stray Light in Optical Cone-Beam Computed Tomography: Techniques for Measurement and Suppression, in preparation for Phys Med Biol
[4] Jordan K and Battista J, 2009 A stable black-refractive-index-matching liquid for optical CT scanning of hydrogels, J of Phys: Conference Series 164: 012045
[5] Jordan K and Battista J, 2009 A transparent black non-diffusing micelle gel for optical CT performance evaluation phantoms, J of Phys: Conference Series 164: 012046