

# Laser cone beam computed tomography scanner geometry for large volume 3D dosimetry

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**Abstract.** A new scanner geometry for fast optical cone-beam computed tomography is reported. The system consists of a low power laser beam, raster scanned, under computer control, through a transparent object in a refractive index matching aquarium. The transmitted beam is scattered from a diffuser screen and detected by a photomultiplier tube. Modest stray light is present in the projection images since only a single ray is present in the object during measurement and there is no imaging optics to introduce further stray light in the form of glare. A scan time of 30 minutes was required for 512 projections with a field of view of 12 x 18 cm. Initial performance from scanning a 15 cm diameter jar with black solutions is presented. Averaged reconstruction coefficients are within 2% along the height of the jar and within the central 85% of diameter, due to the index mismatch of the jar. Agreement with spectrometer measurements was better than 0.5% for a minimum transmission of 4% and within 4% for a dark, 0.1% transmission sample. This geometry's advantages include high dynamic range and low cost of scaling to larger (>15 cm) fields of view.

## 1. Introduction

There are several distinct geometries of optical CT scanners that have been reported for 3D dosimetry applications [1]. These geometries range from broad beam – 2D detector array to *single ray – single detector* systems [2, 3]. Scan speed is an important factor for practical implementation of 3D dosimetry especially in larger volumes. For example, two hours from beginning of an irradiation to completion of data analysis is considered a reasonable goal for 3D gel dosimetry [4]. Fast scanning may be essential for certain applications such as small field dosimetry with strong dose gradients that drive diffusion [5]. Fast scanning is a convenient method to obtain accurate 3D doses compared with conventional dosimeters that require hours or days to map the irradiation field.

While there are many optical CT geometries that provide accurate scanning for small transparent dosimeters, there are few reports on scanning larger dosimeters. For the purposes of this report, large dosimeters are considered to have diameters between 10 and 30 cm. Accuracy is to be maintained within 2% of true attenuation coefficient at the required spatial resolution (typically 1 mm isotropic voxel size). A recent example of performance in a transparent, radiochromic plastic dosimeter has been reported [6]. As the size of the dosimeter increases, the amount of optical scatter and zero dose absorption increase. This places greater importance on stray light correction and dynamic range of scanners. Large polymerization dosimeters that have an increase in optical scatter with dose are particularly challenging for optical CT readout. Efficient phantom scatter rejection has been achieved using telecentric optics and scanned laser beams. However, as the field of view (FOV) increases the

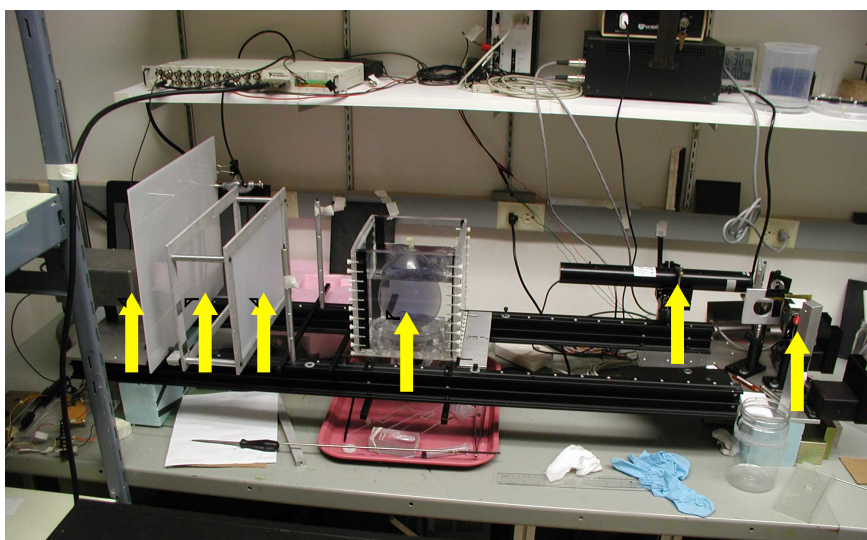


cost of imaging quality, optical components becomes prohibitive for instruments intended for radiotherapy clinics. Fresnel lenses are generally not considered adequate for imaging purposes. But the spatial resolution required for 3D megavoltage dosimetry is lower, approximately 1 mm. At this resolution, Fresnel lenses may be a cost effective approach [7]. There is now a commercial optical CT geometry that includes Fresnel lenses from MGS Research Inc.

In this report, a new optical CT geometry is reported that provides fast and accurate scanning of large dosimeters with less expensive optics. It is based on raster scanning of a single, narrow laser beam in a cone-beam (CBCT) geometry through a large dosimeter, immersed in a refractive index matching aquarium. The transmitted beam is scattered by a thin white film and detected by a single photomultiplier tube avoiding stray light introduced by camera lenses.

## 2. Methods

A photograph of the laser CBCT scanner is shown in Figure 1. The prototype scanner includes: yellow He-Ne laser (attenuated to ~10 microwatts), spectral filter (10 nm bandpass, central wavelength = 594 nm), 1 mm diameter spatial filter, 2D scanning galvo mirror system (Thorlabs), aquarium (FOV = 18 cm), sample jar (15 cm diameter PETE jar, Modus Medical Devices Inc.), diffusive screen detector (white Mylar film), secondary diffuser of white plastic sheet and a photomultiplier tube (PMT). The current from the PMT was amplified with an in-house electronic circuit and digitized with a 12 bit PC based data acquisition card. A Matlab program was developed for cone beam reconstruction using a graphics processing unit (GPU, Nvidia) and CUDA routines. Aqueous carbon black solutions were prepared similar to previous reports, Jordan [8] using Triton X100 (2 mM) and hydrogen peroxide as an anti-microbial agent (1 mM). Absorption coefficients were measured independently with a visible light absorption spectrometer (Hitachi-Perkin Elmer Model 204).



**Figure 1:** Photograph of laser CBCT scanner. Components highlighted by arrows from left to right: photomultiplier tube, secondary diffuser, primary diffuser, aquarium with gel-filled balloon, laser, galvo mirror scanner.

## 3. Results and discussion

Scan time for acquisition of 512 projections, 200 slices, 512 projection samples per slice over a FOV of 17 cm x 12 cm is 30 minutes. Full 3D reconstruction including reading of input data is <20 seconds for a 512x512x200 array.

### 3.1. Spatial resolution

Figure 2, is a transmission image through a plastic ruler, demonstrating submillimeter spatial resolution for the projection images. The full width half maximum of the laser beam was 0.6 mm in the rotation axis reference plane.



**Figure 2:** Transmission image of plastic ruler in scanner rotation axis plane.

### 3.2. Uniformity and accuracy

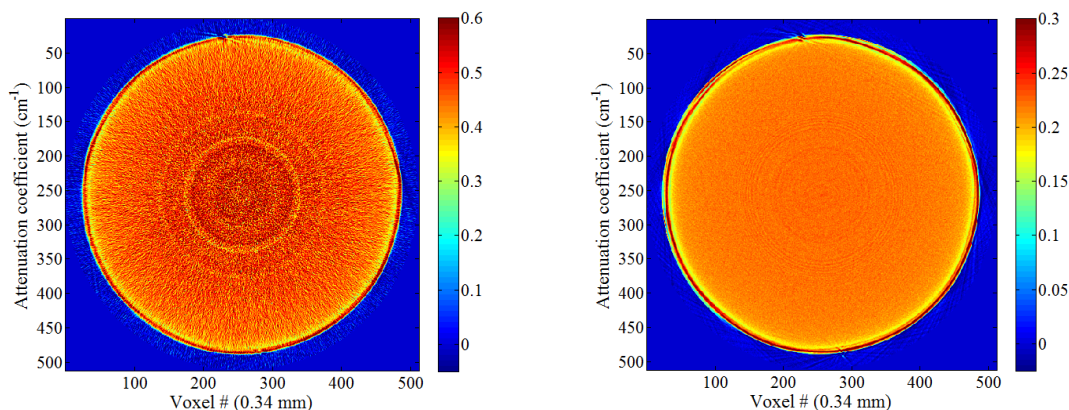
Figure 3, presents a central slice from two carbon black solutions representing a dark object (0.1% transmission) and an intermediate opacity object with transmission of 4%. Figure 4, is a plot of the corresponding horizontal profiles, showing uniformity within 85% of radius. This uniformity varies by only 2% from top to bottom of the jar. Reconstruction ring artifacts are due to reflections within the aquarium system and correction methods including antireflective windows and flat black surfaces are being considered. A large cone of stray light, corresponding to 2% of the laser beam intensity, illuminated the aquarium. The source of this stray light is scatter from the galvo mirrors. Mirror replacement is expected to minimize this stray light component. A stray light measurement was performed by placing a beam block at the entrance of the aquarium and sampling the signal in the shadow. This value was subtracted for each pixel in the projection image, approximating the stray light as a constant. Mean attenuation coefficients for the solutions measured with spectrometer and laser CBCT, were 0.220/ 0.220 and 0.453/ 0.473 ( $\text{cm}^{-1}$ ) respectively. An error in the stray light estimate for the dark solution may be the cause of the CT attenuation being greater than the spectrometer measurement.

## 4. Conclusion

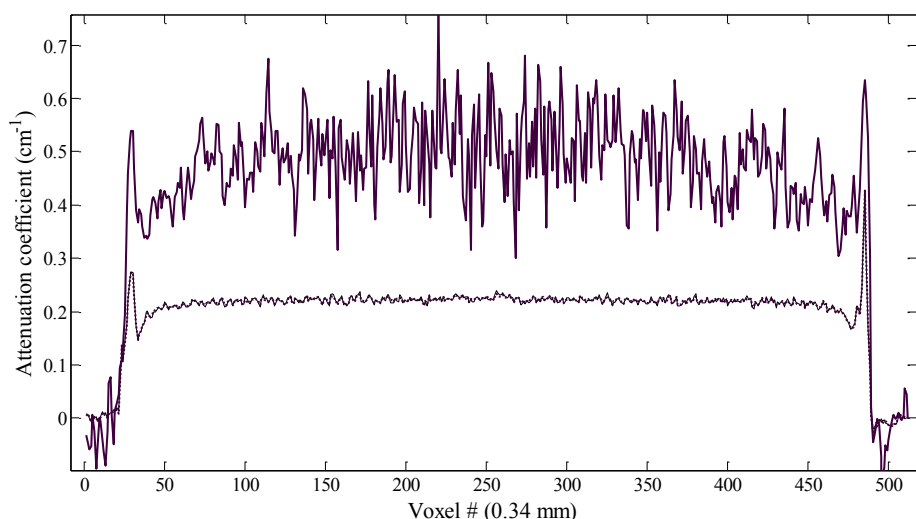
The combination of raster sweeping a single laser beam and a single, large-area detector provides a quantitative, tomographic optical CBCT scanner geometry for fast 3D measurements of large dosimeters. A scan time of 30 minutes was demonstrated for a FOV of 12 x18 cm. Uniformity to within 2% of the mean value was recorded over the useful 12 cm jar height and the central 85% radially. The use of vessels with lower refractive indexes would allow quantitative scanning of a larger fraction of the dosimeter volume. The single-ray single-detector geometry provides excellent stray light rejection for large FOV's. Stray light rejection is important for quantitative, high dynamic range optical CT scanning of large dosimeters that can represent patient volumes exposed in radiotherapy.

## 5. Acknowledgements

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**Figure 3:** Central transverse slices for reconstructions with carbon black solutions in 15 cm jars with 0.1% (left) and 4% (right) transmission along central ray. Note that the two rings in darker, left image have been attributed to stray reflections within the aquarium.



**Figure 4:** Horizontal, central profiles for reconstructed slices of phantoms of Figure 3. Note the uniform response is limited to the central 85% of the diameter due to the refractive mismatch of the contained solution and jar wall.

## 6. References

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