Dual wavelength optical CT scanning of anthropomorphic shaped 3D dosimeters

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Abstract. To create an optical density map of 3D dosimeter phantoms, the ratio of the transmission profile (either a line or planar) acquired after irradiation of the dosimeter and a pre-irradiation reference scan of the same dosimeter phantom is taken. Any uncertainty in repositioning of the phantom may result in an uncertainty in the optical density map and finally also in the derived dose maps. Correct repositioning is paramount when scanning non-cylindrical dosimeter phantoms as any repositioning error will give rise to severe imaging artifacts. We hereby propose a different scanning technique that does not require any repositioning of the dosimeter phantom. In this method, no pre-irradiation scan is recorded but the dosimeter phantom is scanned twice with light at two different wavelengths. It is demonstrated that this method is accurate in scanning non-cylindrical anthropomorphic shaped phantoms.

1. Introduction

Three-dimensional radiation dosimetry has received growing interest with the implementation of highly conformal radiotherapy treatments [1]. Much research has been conducted towards both the development of different radiation sensitive three-dimensional dosimeters and adequate scanning techniques. Although an acceptable precision and accuracy has been achieved with polymer gel dosimeters and MRI scanning [2-4], the procedure is relatively labor intensive and some expertise is needed to acquire reliable quantitative MR images. As an alternative to MR scanning, optical CT scanning has been proposed as an alternative [5]. Different staining dosimeters have been proposed as a better alternative to polymer gel dosimeters including polyurethane based dosimeters, PRESAGE™ [6] and micelle gel dosimeters [7, 8] and another system will be proposed at this conference.

In 3D radiation dosimetry with optical CT scanning readout, projections of transmitted light are recorded in either lines or planar by use of an optical CT laser scanner or cone beam CT scanner using a CCD camera respectively. Dose maps are acquired by taking a blank (reference) scan of the dosimeter phantom prior to irradiation and a scan of the dosimeter phantom after irradiation. The change in optical density that is a measure of the absorbed radiation dose can then be easily obtained by taking the logarithm of the ratio of the dark current corrected reference scan and data scan. Absolute dose maps can be derived from the optical density maps by calibration of the optical absorption coefficients to dose values. The method using a pre-irradiation reference scan and post-irradiation scan relies on the repositioning and scanning of the dosimeter in exactly the same position.
Accurate repositioning becomes even more crucial when scanning anthropomorphic shaped and deformable dosimeter phantoms.

2. Methods and Materials

The principle behind dual wavelength scanning is that the radiation sensitive dye in the dosimeter has a selective absorption for light of a particular wavelength (figure 1a). As a result, only light with that specific wavelength will be absorbed by the dye while any impurities such as impurities or Schlieren will cause attenuation in the transmitted light projection scan at both wavelengths (figure 1b).

Two different scanner types have been modified for scanning at two different wavelengths. The first type of scanner is an in house constructed CT laser scanner (figure 2a) where a second green laser is added and is directed onto the galvano-mirror by use of broadband half-reflecting mirrors. The second type of scanner is rebuilt from a cone beam Modus Vista™ scanner (figure 2b).

![Figure 1](image1.png)

**Figure 1.** Absorption spectrum of Flexydos3D, a new staining dosimeter (a) with an absorption peak at red light wavelengths (a) and basic principle of dual wavelength scanning (b). The inset of (a) shows the measured spectrum of the different cone beam optical CT scanner light sources.

![Figure 2](image2.png)

**Figure 2.** Optical laser CT scanner equipped with a second green laser that is focused on the same galvano-mirror as the red laser (a) and an optical cone beam scanner equipped with new light sources at three different wavelengths (b).
The CCD camera in the Modus scanner is recognized as DragonFly2 DR2-HIBW. The light source of the scanner has been replaced by a flat bed diffuse light source panel in which the principle colours (red, green, blue) can be selected. The driver for the LED light source was developed in house and is based on a simple bipolar transistor circuit. The light intensity of each of the colours can be adjusted to optimise the dynamic range without adjusting the exposure time or gain of the CCD camera. All reconstruction software for both scanners is developed in house in Matlab code and takes into account the difference in light intensities and wavelength dependent sensitivity of the detector.

Projection maps of optical density difference between the red and green light projections are calculated prior to the cone beam reconstruction. As shown in equation 1, the blank projections drop out of the equation:

\[
\Delta OD_{\lambda} = 530 \text{ nm} \cdot OD_{\lambda} = 630 \text{ nm} - OD_{\lambda} = 530 \text{ nm} = \log 10 I_{\lambda = 530 \text{ nm}} - I_d \lambda = 630 \text{ nm} - I_d
\]

where \( I_{\lambda} \) is the measured intensity in a pixel of the projection image recorded with central wavelength \( \lambda \) and \( I_d \) is the dark current. It is assumed that the blank current is the same for both wavelengths, which is easily obtained by scaling the intensity of the projection images on the basis of the background signal intensity (i.e. next to the phantom). Then a cone beam reconstruction is performed on the optical density difference projection images. From figure 1, it can be seen that there is nearly no light absorption by the leucodye, which implies that \( I_{\lambda = 530 \text{ nm}} \approx 10 \). This is also apparent from figure 4a where the square beam is invisible. It is imperative that this is not a necessary condition for this method to work.

3. Results and Discussion

3.1. Spatial accuracy QA phantom

In order to check the reliability of scanning a non-cylindrical phantom, a spherical phantom (figure 3) and other non-cylindrical test phantoms have been scanned. A grid pattern was created in these phantoms by use of syringes arranged in a regular pattern.
After removal of the syringes, the cavities were filled with a colored gel. Intensity differences in
the grid pattern are related to deviations in the diameter of the needle cavities and are not attributed to
optical effects.

3.2. Square photon beam

Figure 4 demonstrates the difference in absorption of red and green laser light by the leucodye after
exposure of a micelle gel dosimeter to a square photon beam.

![Axial OD maps scanned with a 530 nm green laser (a) and with a 630 nm red laser (b) and
reconstructed longitudinal dose map along the beam axis with depth dose profile (c).]

Figure 4.

4. Conclusion

Dual wavelength scanning avoids the need for a blank pre-irradiation scan, hence diminishing any
imaging artifacts related to a non-accurate repositioning of the phantom in the optical scanner. This is
particularly helpful in scanning anthropomorphic shaped dosimeter phantoms. In principle, it is possible
to perform dual wavelength scanning by use of a broadband light source and using optical filters at the
detector side or a color CCD camera with significant dynamic range at each of the principle colors.
This would speed up the optical scanning process with a factor of two.

5. Acknowledgements

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photon beam (figure 4) at Chris O’Brien Lifehouse.

6. References

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