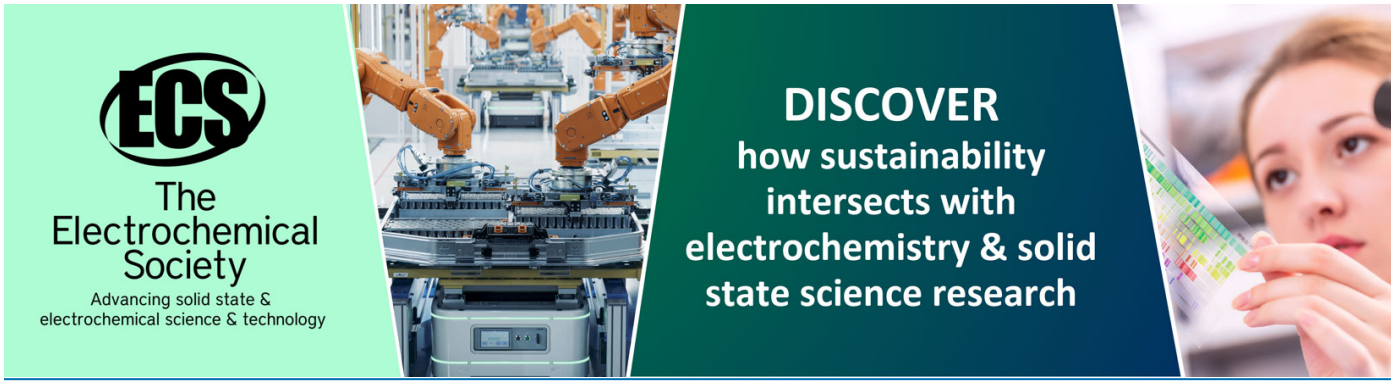
Characterization of a cone beam optical scanner



Characterization of a cone beam optical scanner

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Abstract. The use of radiochromic FX gel for mapping 3D dose distribution is hampered by the diffusion of gel and the slow scanning techniques. The development of fast optical cone beam scanning has improved the chances of using radiochromic gel as a feasible dosimeter for radiotherapy applications. In this work an optical cone beam scanner has been developed in-house and its performance characteristics have been studied. The reconstructed image of the optical scanner was analyzed by studying the resolution, signal-to-noise ratio and contrast to noise ratio (CNR). The resolution of the optical cone beam CT scanner was studied by scanning a catheter of 1 mm outer diameter and the scanner was able to detect the catheter. The geometrical accuracy of the reconstruction was studied by placing catheters in spiral geometry in the gel phantom and measuring the distances. It has been observed that the in-house Optical Cone beam scanner is suitable for scanning radiochromic gels for radiotherapy applications.

1. Introduction

Over the half decade, external beam radiation therapy has improved due to i) the advance of high-energy linear accelerator with computer controlled multileaf collimators (MLCs) and on-line imaging, ii) the development of improved imaging to localize tumors for treatment planning, and iii) significant advancement in the treatment planning system with more robust dose calculation algorithms and the implementation of the inverse planning modules. One of the challenges with newer radiation delivery techniques that aim at precise delivery of radiation dose is to develop an accurate and efficient dosimetry system capable of providing full three-dimensional dose distribution. It has been accepted that patient specific quality assurance of radiation dose delivered is to be performed for intensity modulated radiotherapy techniques. Ion Chamber, TLD and film have been routinely used for these measurements. However, ion chamber can only provide point dose and although film can provide two dimensional dose distributions; has its limitations for absorbed dose measurements. Several authors have investigated the use of Fricke gel dosimeters. However, due to issues of diffusion [1, 2], alternative polymer gel dosimeters were developed.

Polymer gel dosimeters are manufactured from radiation sensitive chemicals, which upon irradiation polymerize as a function of the absorbed radiation dose [3]. These gel dosimeters which record the radiation dose distribution in three-dimensions (3D) have specific advantages when compared to one-dimensional dosimeters and two-dimensional dosimeters [4]. These 3D dosimeters are radiologically soft-tissue equivalent [5, 6] with properties that may be modified depending on the application. The 3D radiation dose distribution in polymer gel dosimeters may be imaged using magnetic resonance imaging (MRI) [7, 8], optical-computerized tomography (optical-CT) [9-11], x-ray CT [12, 13], ultrasound [14-16] or vibrational spectroscopy [17,18].

Due to the practical problems in availability and cost of MRI, optical scanning of gel has been used by several researchers as a more accurate and practical alternative to MRI.

Also, the use of radiochromic gel with optical scanning has issues such diffusion and hence optical scanning has not been predominantly used for obtaining dose distribution. However, volumetric scanning with optical cone beam CT has considerably reduced the scanning time and also provides full volumetric information of the dose matrix embedded in the gel. An optical cone beam CT (CBCT) scanner has been developed in this department and it is necessary to characterize the scanner before use [19, 20]. In this paper we discuss the construction and performance characteristics of an in-house optical cone beam CT scanner for use in radiotherapy dosimetry.

2. Methods and Materials

2.1. Development of Optical Cone Beam Scanner

2.1.1. Optical Cone Beam Scanner specifications

An optical cone beam CT scanner consists of a uniform light source, an aquarium with a turntable and a CCD camera (figure 1). LED array containing 192 LEDs of wavelength 540 nm is placed in a circular geometry and modified as a flat light source by placing a diffuser at 20 cm distance in front of the LEDs. The light source illuminating the container was collimated to 10 x 15 cm to reduce the scattered light reaching the camera. The turntable is attached to a four-pole stepper motor with reduction gear that reduces the step angle from 1.8 degrees to one degree. The stepper motor is interfaced to a computer through a simple driver circuit that uses UNL 2004 IC and is connected to the parallel port of the PC. The PointGray® CCD camera is also controlled by this PC. The gain, brightness, shutter timing and image acquisition are controlled by the software.

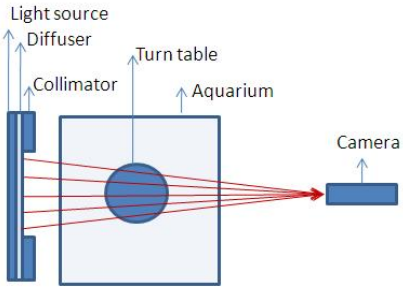

Figure 1: Schematic representation of the Optical Scanner.

2.1.2. Gel Phantom

In this work we used FX gel prepared by adding 4% Gelatin to 50 mM H_2SO_4, 0.5 mM ferrous ammonium sulphate and 0.05mM xylenol orange at 37ºC in a water bath. The gel phantom was refrigerated at 5ºC for about 4 hours for gelation and brought to room temperature before irradiation. The gel was prepared in a thin walled polystyrene cylinder of diameter 10 cm and height 15 cm. However, in this work on characterization of the scanner, for certain experiments, liquid that simulate the optical attenuation properties of gel has been used.

2.1.3. Image acquisition Software

The software for driving the stepper motor and for acquiring the image from the camera has been developed with visual basic. The user is required to select between the two scanning modes available, i.e half rotation scan or full rotation scan. Half rotation scan acquires images for 194º (i.e 180º plus the cone angle) and full cone beam acquires images for 360º. In order to obtain the optical attenuation coefficients, the gel phantom is scanned twice, once before irradiation of the gel (pre-scan) and then after the irradiation (post scan). The software has a provision to either select the pre-scan or the post-

scan. The images are acquired at every degree of rotation and stored in bitmap format in the respective folder created for pre-scan or post scan. The software also has provision to adjust the gain and the shutter values of the camera for each scan.

2.1.4. CT reconstruction

The image reconstruction codes have been developed using MATLAB®. Two routines have been developed in Matlab, one to stack the acquired images in to a 3D dataset as pre-scan and post-scan image sets and the other to perform the reconstruction. Each image acquired is of size 640 x 480 pixels and for a half-rotation scan there will be 194 such images. This routine stacks all the 2D image matrices together to form a 3D matrix of size 194 x 640 x 480 for a half cone beam acquisition and similarly a matrix of 360 x 640 x 480 for full cone beam acquisition. This is performed for both the pre-scan and post-scan images and stored in separate user defined files. The second routine reads these files as input and determines the attenuation coefficient for each pixel and reconstructs the selected plane using the 'ifanbeam' function implemented in Matlab. A bespoke FDK based 3D reconstruction software was also developed for the optical cone beam scanner and the details of which are mentioned elsewhere [21].

2.1.5. Characterization of the Optical cone beam CT scanner

Uniformity, resolution, contrast and sensitivity of the optical CBCT scanner were verified using methods similar to those suggested by Oldham *et al* [22]. Uniformity was checked by scanning a liquid with a color solution having attenuation coefficient similar to gel irradiated at 1 Gy. The uniformity of the 2D reconstruction of the attenuation coefficient (μ) was verified by measuring the mean μ in the region of interest (ROI) of 10 x 10 pixels.

To quantify the spatial resolution and geometrical distortion of the scanner, a phantom similar to the spiral needle phantom [22] was fabricated using capillaries of 1.5 mm diameter. The modulation transfer function (MTF) was used to quantify the spatial-frequency response characteristics of the optical-CT. The contrast resolution at various points in the gel phantom was verified using a finger phantom [22]. Three different liquids with varying attenuation were used. The SNR and CNR for the fingers of varying attenuation coefficients were calculated using the formula given below.

$$SNR = 20_{log}\,(A_{mean}/\,\sigma_B)\ in\ dB$$

Where, A is the region of interest in the image and σB is the standard deviation of points in the background region.

$$CNR = A_{mean} - B_{mean}/\sigma_B$$

Where, A is the region of interest in the image and B is the background region in the image.

3. Results

The uniformity was within ±5% in the central region except for one point where it was 8% and varied to about 20% at points close to the wall of the gel container. The contrast resolution observed with the finger phantom was found to be acceptable. The measurement of spatial resolution showed that a capillary of size 1.5mm diameter could be well resolved with the Opt. CBCT scanner. However, the artefacts near the wall were seen to affect the measurement.

The magnified image of the 0.9 mm copper wire phantom is shown in Fig. 2(a). The full-width at half-maximum of the reconstructed wire was 1.06 mm. the radon transform of the images were obtained using the radon function of MatLAB. The MTF was computed by fast Fourier transform of the Radon transform of the images, and the results are shown in Fig 2(c). The system has sub millimetre resolution as the MTF was greater than 10% out to approximately 0.9 mm-1 on the average.

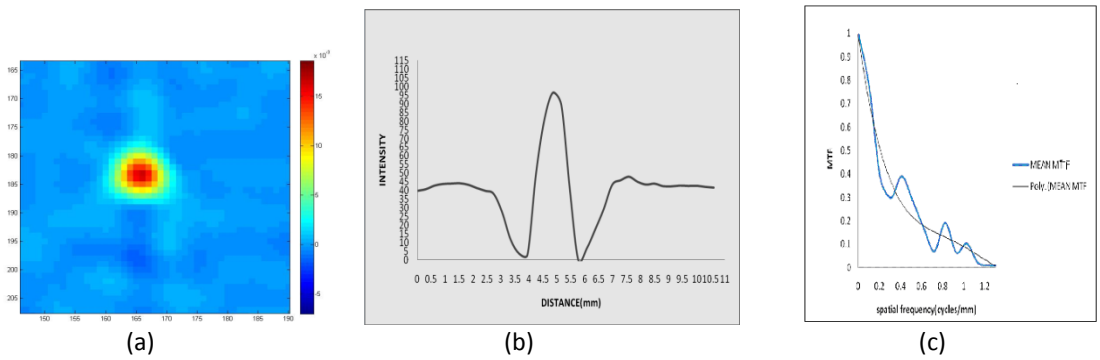

Figure 2: (a) Magnified reconstructed image of thin copper wire of thickness 0.9mm (b) FWHM profile of copper wire (c) MTF plot of copper wire

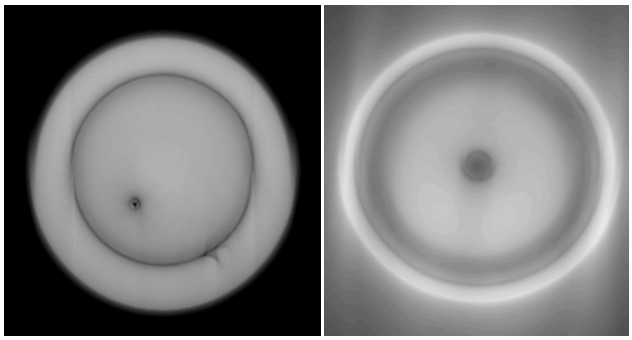

Figure 3: a) reconstructed image of the capillary b) reconstructed image of the finger phantom using FDK based reconstruction software

4. Conclusion

An optical CBCT scanner has been constructed for reading the dose distribution embedded in the gel matrix. Its performance characteristics like uniformity, spatial and contrast resolutions and sensitivity were studied and results were found to be promising. Software based on FDK algorithm for volumetric reconstruction has been developed and ensured acceptable results.

5. References

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