Three Dimensional (3D) Radiation Dosimetry based on Optically Stimulated Fluorescence Computed Tomography of a Novel DNA Dosimeter

ENPH 455
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INTRODUCTION & OBJECTIVES

A novel form of dosimetry using **fluorophore-marked DNA fragments** may provide a powerful platform for future **high-sensitivity** and **spatially-resolved** dose measurements for all radiation types. [1]

The present work assesses DNA's adaptability to **three-dimensional computed tomography** in the context of quality assurance for oncological radiation therapy.

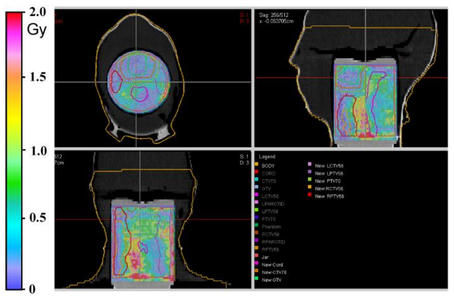


FIGURE 3: *(Above)* An irradiated dosimeter phantom used for validating the delivery of a radiation treatment plan. [4]

FIGURE 1: *(Below)* Illustration of the dosimetry mechanism. The quencher (Q) suppresses the fluorescence response of the reporter (R) until the DNA fragment is severed by radiation. [1,2]

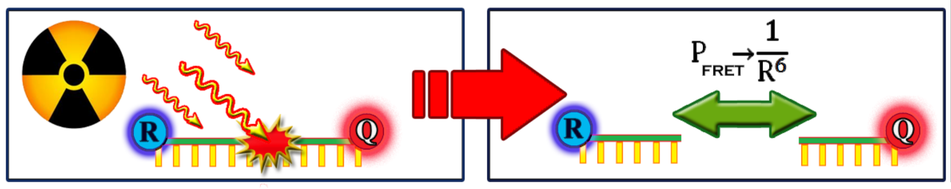
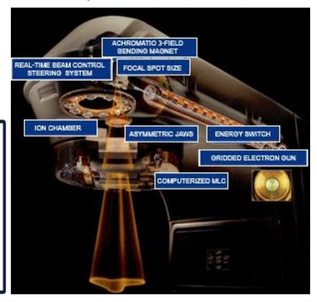


FIGURE 2: *(Right)* State-of-the-art medical LINACs offer complex control over beam topology, intensity, and orientation. [3]



APPARATUS DESIGN

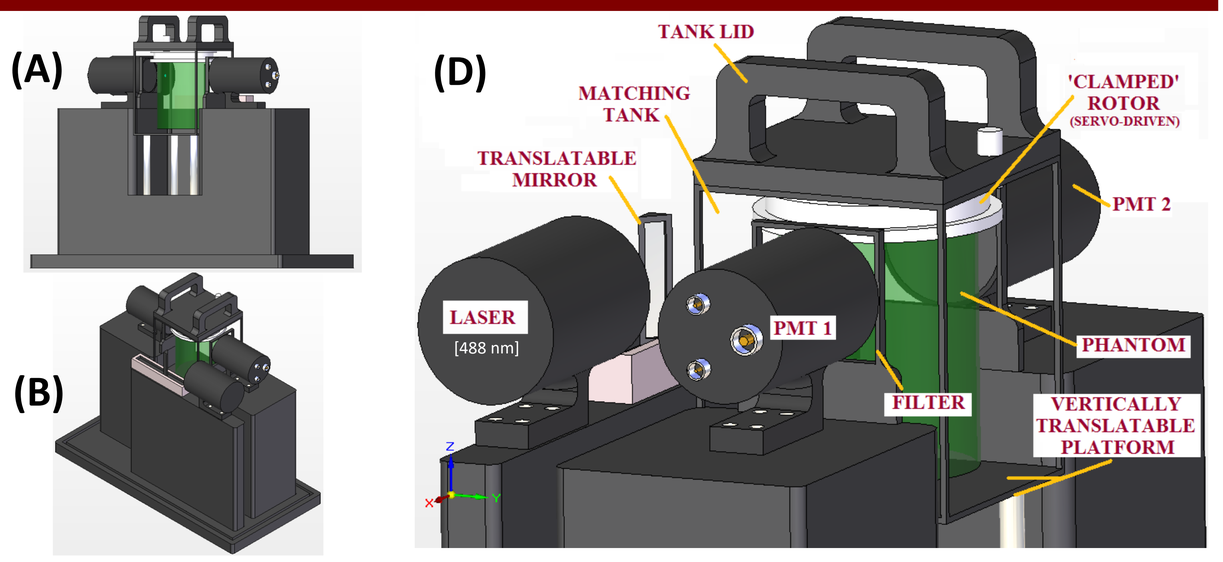


FIGURE 6: Computer rendition of apparatus design showing: (A) rear perspective; (B) isometric view; (C) top view with lid removed while operating; (D) system details. The base measures 22 cm by 44 cm. Degrees of freedom are provided by a translatable mirror, rotatable phantom clamp, and vertical platform. An opaque case covers the apparatus while in use.

KEY FEATURES

PHANTOM	• 5% gelatine-in-water solution with 0.5 µM DNA in a thin-walled 8 cm (φ) PETE jar. [6,7] • 2.7 nM of fluorescing DNA per Gray of local radiation dose, 70% quantum efficiency. [7]
EXCITATION BEAM	• 488 nm Argon laser pulsed at 100 mW, 28 ms, 2 mm^2 CS. (photobleach loss < 2%). [7] • 10-12% propylene glycol-water mix for index matching between tank and phantom. [6]
DETECTORS	• GaAs(Cs) or multi-alkali PMTs with charge-integrating and gated electronics. [8,9] • 496 nm long-pass optical filters to block laser scatter; entire setup flat against tank. [10]
SCAN ROUTINE & TIME	• 40 translational steps and 90 angular steps = 3600 measurements per 2 mm slice. • 2.24 seconds per angle, 3.36 minutes per slice, 2.8 hours for a 10 cm long phantom.
ESTIMATED COSTS	• Roughly $100 per phantom at present dual-labelled DNA prices. [11] • Estimated $10,520 for self-assembled apparatus (excluding 488 nm laser). [11]
NUMERICAL MODEL & SIMULATION	• Generates finite-element map; emulates excitation beam, fluorescence physics; computes detector cross-sections and signal attenuation; models proportional detector response. • Post-processing applies custom digital filter and nearest-neighbour interpolative reconstruction.

PROPOSED SOLUTION

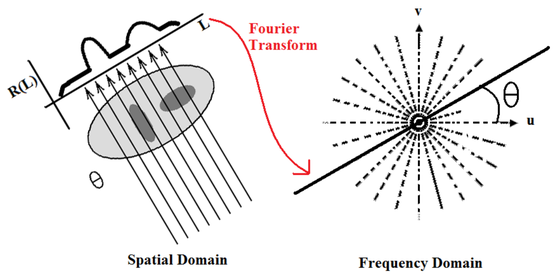
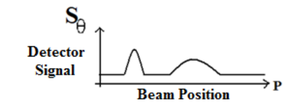
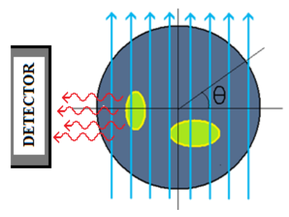


FIGURE 5: *(Below)* Proposed approach: Fluorescence readings are taken while a well-defined excitation beam translates across the phantom. Measurements from multiple angles are then combined via the Fourier Slice Theorem and numerical 'back projection'.





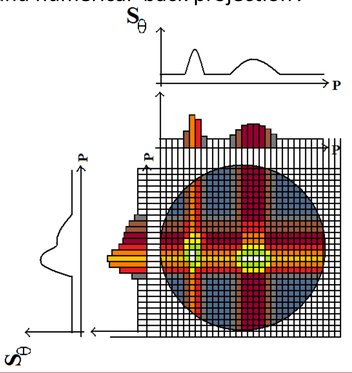


FIGURE 4: *(Above)* Typical CT reconstructions rely on the Fourier Slice Theorem. Measurements of beam attenuation (R) are taken at different angles to sample the object's frequency domain. An inverse Fourier Transform then produces a reconstructed cross-sectional image. [5]

SIMULATION, FILTERING, & RESULTS

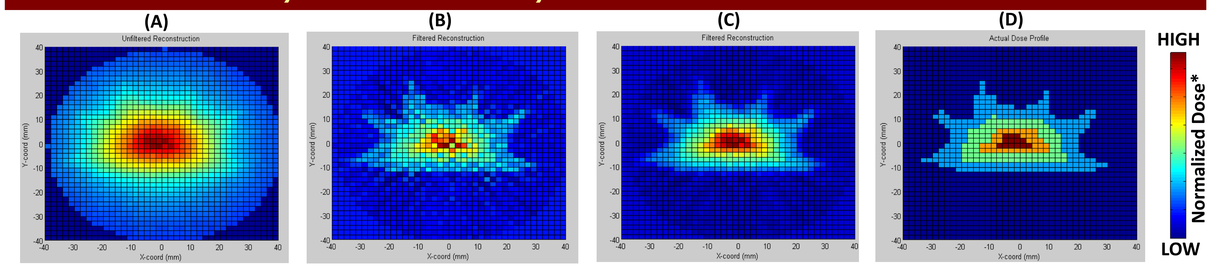


FIGURE 7: *(Above)* Impact of digital filtering on reconstruction quality: (A) unfiltered dose profile; (B) results with ramp filter; (C) results with modified Shepp-Logan filter; (D) true dose profile resembling a "7-field" prostate treatment. [11]

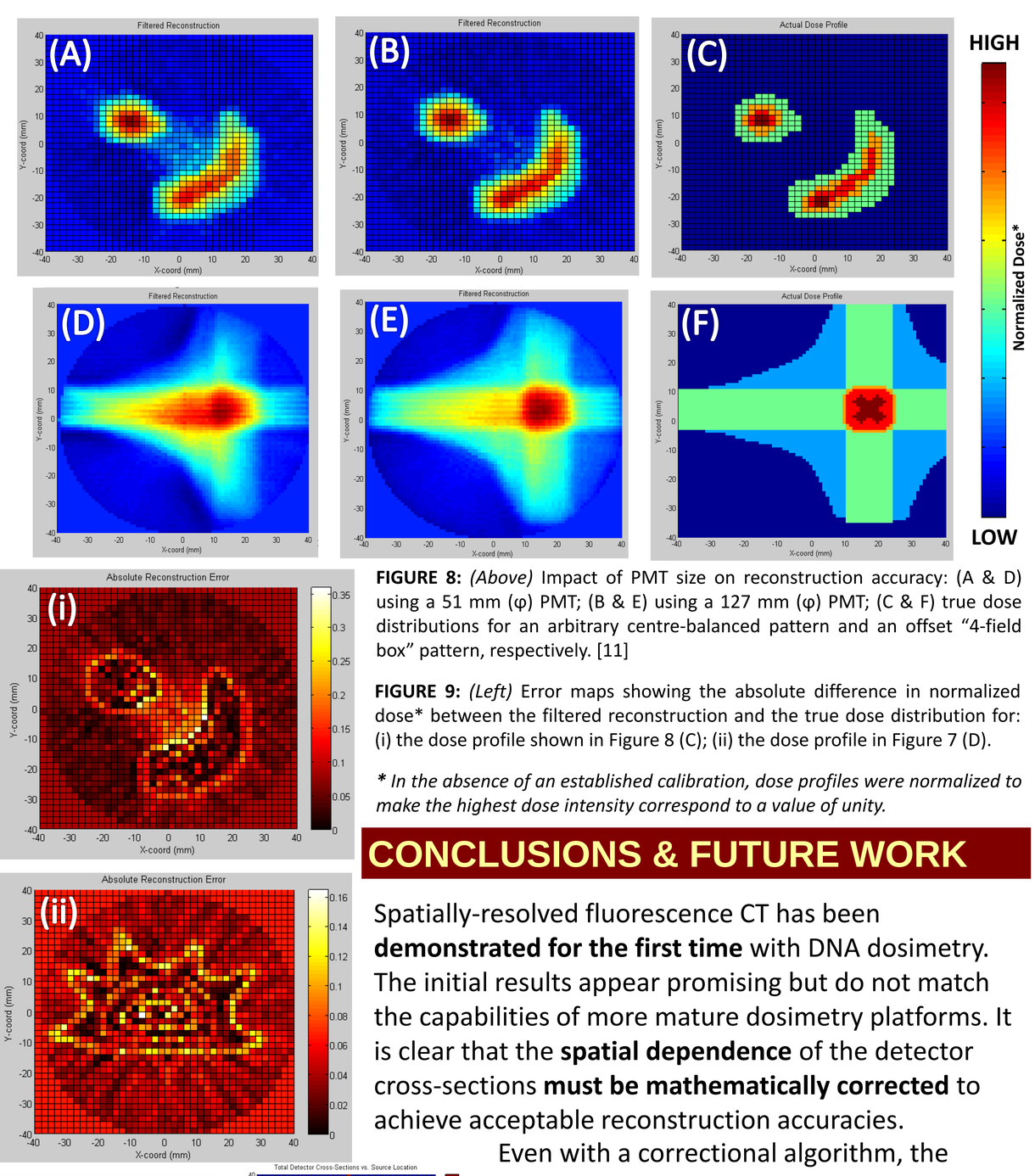


FIGURE 8: *(Above)* Impact of PMT size on reconstruction accuracy: (A & D) using a 51 mm (φ) PMT; (B & E) using a 127 mm (φ) PMT; (C & F) true dose distributions for an arbitrary centre-balanced pattern and an offset "4-field box" pattern, respectively. [11]

FIGURE 9: *(Left)* Error maps showing the absolute difference in normalized dose* between the filtered reconstruction and the true dose distribution for: (i) the dose profile shown in Figure 8 (C); (ii) the dose profile in Figure 7 (D).

** In the absence of an established calibration, dose profiles were normalized to make the highest dose intensity correspond to a value of unity.*

CONCLUSIONS & FUTURE WORK

Spatially-resolved fluorescence CT has been **demonstrated for the first time** with DNA dosimetry. The initial results appear promising but do not match the capabilities of more mature dosimetry platforms. It is clear that the **spatial dependence** of the detector cross-sections **must be mathematically corrected** to achieve acceptable reconstruction accuracies.

Even with a correctional algorithm, the technique may remain ill-suited to scenarios requiring large phantom sizes or fast scan times.

Future work should attempt experimental realization and establish **calibration schemes** to obtain a direct correlation between measured values and **true dose magnitudes**.

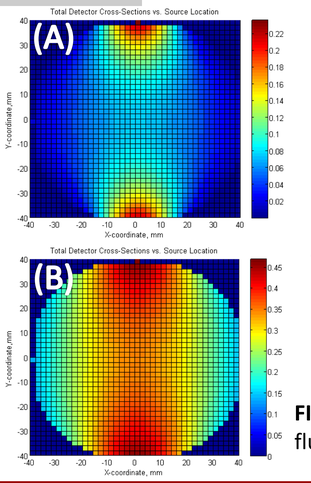


FIGURE 10: *(Left)* Total detector cross-sections as a function of fluorescence source for: (A) 51 mm (φ) PMT; (B) 127 mm (φ) PMT.

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[5] Buzug T. M. **Computed Tomography: From Photon Statistics to Modern Cone-Beam CT**. *Springer*, Berlin (2008), pp. 31-46, 151-183.

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[7] Email correspondence with Tara Wood, October 13th, October 24th, & November 17th 2012.

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[11] Marchildon R. P. **Three Dimensional Radiation Dosimetry Based on Optically Stimulated Fluorescence Computed Tomography of a Novel DNA Dosimeter.** BScE Thesis, Dept. Of Phys, Queen's University, Kingston, ON, Canada (2012).

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