Development of a 3D Dose Reconstruction Algorithm for Volumetric Plastic Scintillation Detectors

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Introduction: Dose measurement is a critical component for quality assurance and verification of accurate dose calculation and delivery in radiation therapy. Conventional verification methods primarily rely on two-dimensional detectors that sample a single plane of the dose distribution for comparison with treatment planning system calculations. As a result, these methods provide only limited information about the true three-dimensional dose delivered to patients. Existing commercial 3D dosimeters are often restricted to specific applications, such as depth-dose or range modulation measurements, and suffer from limited spatial resolution dictated by detector size and spacing. In addition, many current detectors are composed of non-tissue-equivalent materials such as metal and air.

Motivation: The purpose of this project is to develop a 3D dose reconstruction algorithm capable of generating volumetric dose distributions measured with large plastic scintillation detectors irradiated with photon, electron, and proton beams used in radiation therapy.

Methods: An algorithm was developed to reconstruct 3D dose distributions measured with a volumetric, tissue-equivalent plastic scintillator detector. This algorithm is based on the back-projection of the 2D-dose distributions obtained from the images of the scintillation light captured with cameras that are positioned around the plastic scintillator. The cameras were installed on multiple sides of a large plastic scintillator block (20 × 30 × 30 cm³) and housed in a light-tight chamber to collect simultaneously the scintillation light induced by radiation.

Results: The reconstructed 3D dose distributions demonstrated the feasibility and effectiveness of plastic scintillators as large, water-equivalent volumetric dosimeters (Fig. 1a). Dose profiles along the lateral (X and Y) directions and depth-dose curves were simultaneously extracted from a single-shot irradiation using photon, electron or proton beams (Fig. 1b). For proton beams, beam ranges were accurately determined from the reconstructed volumetric dose distributions for each beam used in the treatment of different sites. Although the plastic scintillators provided a continuous medium with inherently high spatial resolution, the reconstructed dose resolution was limited by the camera digitization resolution (0.25 mm) of the dose projections. Dose linearity was influenced by the camera response and sensitivity to the different levels of the emitted scintillation light. The reconstruction accuracy depended on the optical transmission properties of the scintillator and the number of the dose projections obtained by the cameras surrounding the detector.

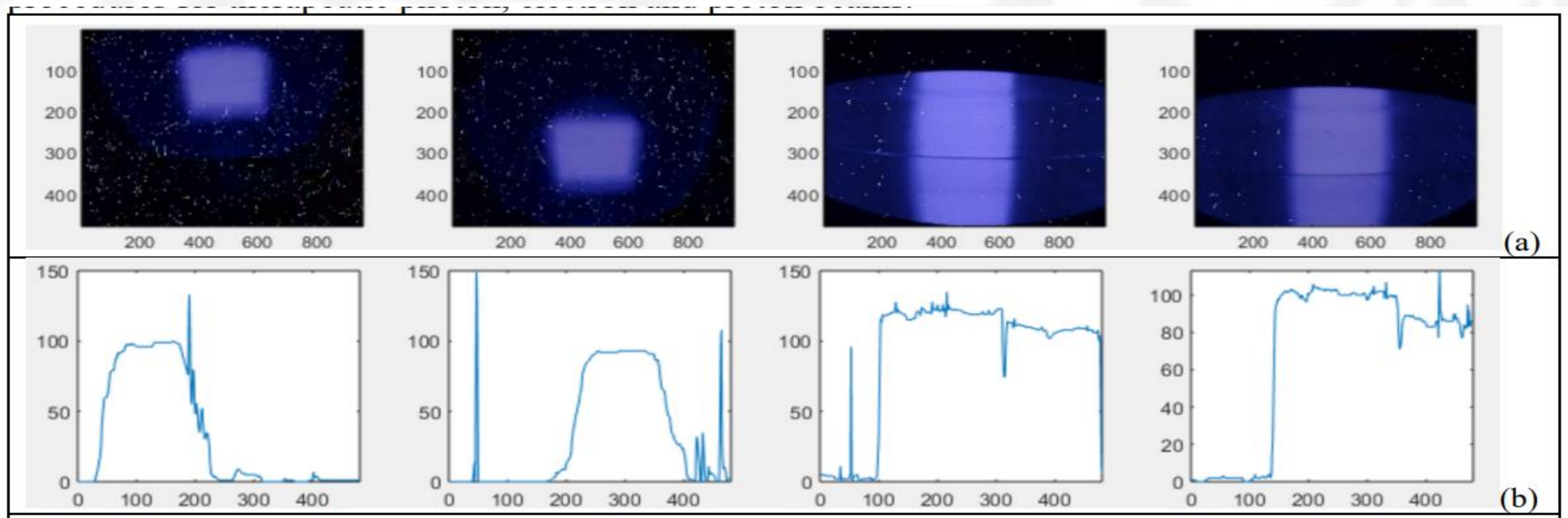

Figure 1: (a) The scintillation light obtained from different four cameras installed from different sides of the detector used for the dose projections. (b) Dose profiles and depth dose curves obtained from the 3D dose distributions for a 6 MV photon beam.

Conclusion: Three-dimensional dose reconstruction using plastic scintillation detectors shows strong potential to advance the dosimetry techniques in radiation therapy. These detectors offer tissue-equivalent, large-volume 3D dose measurements with high spatial resolution and enable comprehensive quality assurance for therapeutic photon, electron, and proton beams.

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