Optimization of Optical Dosimetry in a Water Phantom by Exploiting Cherenkov Radiation Polarization Imaging

Gérémy Michaud[1,2], Émily Cloutier[1,2], Anastasiia Pusenkova[4], Tigran Galstian[3,4], Louis Archambault[1,2] et Luc Beaulieu[1,2]

[1]Département de physique, génie physique et d'optique et Centre de recherche sur le cancer, Université Laval, Québec, Canada

[2]Service de physique médicale et de radioprotection, Centre intégré de cancérologie, CHU de Québec-Université Laval et Centre de recherche du CHU de Québec, Québec, Québec, Canada

[3]Département de physique, génie physique et d'optique et Centre d'optique, photonique et lasers, Université Laval, Québec, Canada

[4]Patqer Photonique Inc., Québec, Canada

Introduction: Cherenkov radiation occurs when a charged particle travels through a dielectric medium at a speed greater than that of light [1]. This phenomenon generates polarized light, which can be utilized to detect and quantify radiation dose distributions in medical applications such as radiotherapy [2]. By using Cherenkov light emitted from the irradiated medium, this promising method allows real-time assessment of dose distribution [3]. Building upon previous research [4, 5], this study aims to characterize a novel, electro-optic polarizer system for in-water quantitative Cherenkov measurements.

Methods: Cherenkov emission is captured using a camera equipped with a charge-coupled device image sensor during the irradiation of a water tank with dimensions of $15 \times 15 \times 20\,\mathrm{cm}^3$ by photon and electron beams of varying energies, namely 6 MV, 18 MV, 6 MeV, and 18 MeV. Analysis of Cherenkov radiation polarization is performed using a rotating linear polarizer alongside an innovative polarization modulator developed by PATQER Photonique. This approach effectively extracts the polarized component of the signal, the average polarization angle, and the non-polarized portion of the signal without requiring any mechanical movements. Reference data is obtained from radiochromic films and a treatment planning system.

Results: The measurements yield the normalized dose profile relative to the maximum irradiation dose and the depth dose profiles of the ionizing beam. For multiple 16-bit pictures, the mean gray value in the region of interest inside the emission beam (shown in the figure 1) was found to be 2.67×10^4 counts, with a standard deviation of 8.40×10^1 counts. These findings confirm the high reliability and reproducibility of this approach, validating the feasibility and relevance for accurate real-time assessment of dose distribution in radiotherapy.

Conclusion: Further studies could explore the application of this dosimetric method in clinical scenarios, including evaluating the FLASH effect [2]. Moreover, a hybrid approach, combining the advantages of optical dosimetry with other dose measurement modalities, could be developed for comprehensive and precise dose distribution assessment in radiotherapy.

Figures

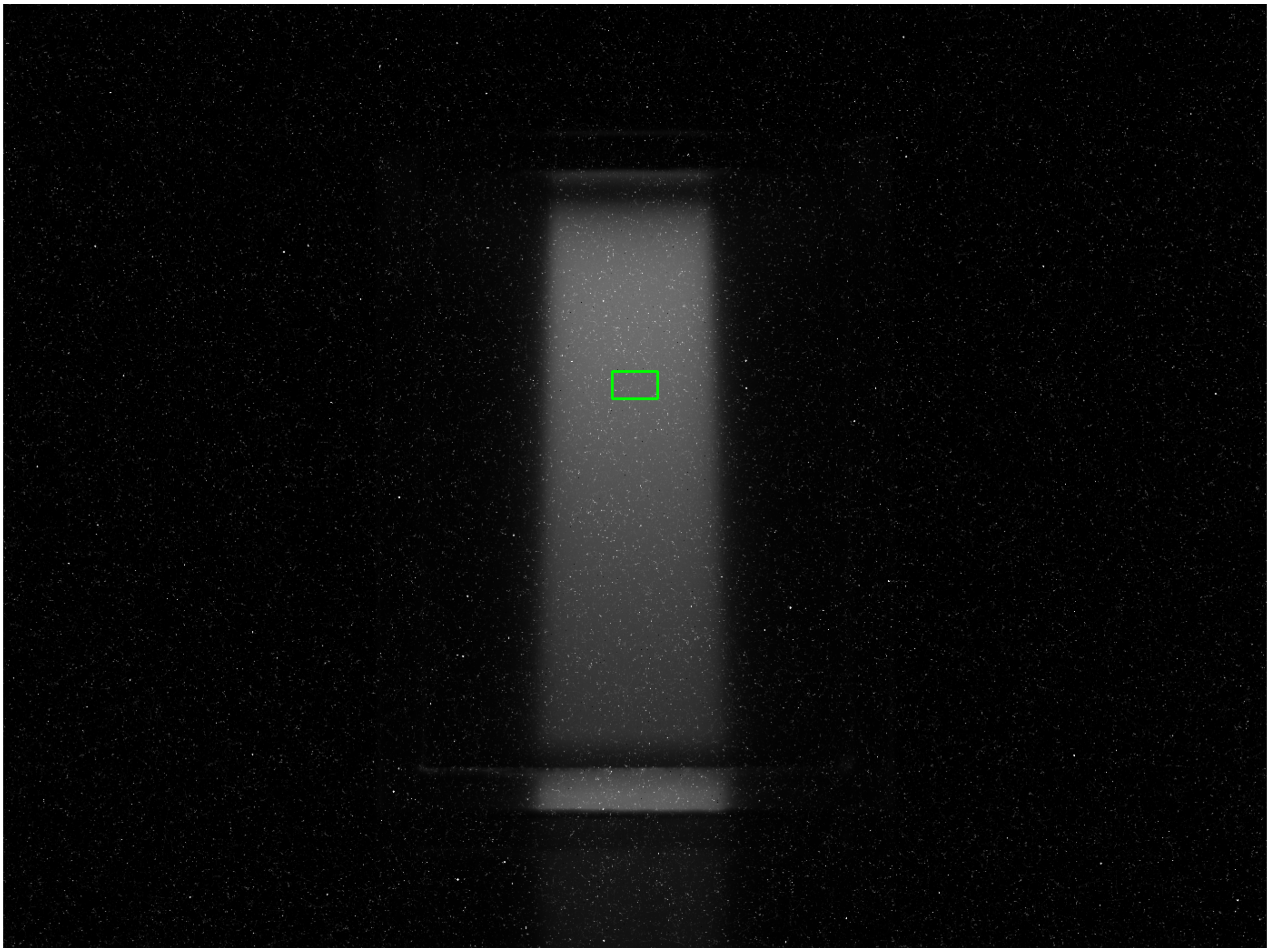

Figure 1: Region of interest (ROI) delineated in vivid green, representing the area for computation of the average gray value within the Cherenkov emission beam generated by an 18 MV energy photon beam.

References

[1] P. A. Čerenkov, "Visible Radiation Produced by Electrons Moving in a Medium with Velocities Exceeding that of Light", Physical Review **52**, 378–379 (1937).

[2] M. R. Ashraf, M. Rahman, R. Zhang, B. B. Williams, D. J. Gladstone, B. W. Pogue, and P. Bruza, "Dosimetry for FLASH Radiotherapy: A Review of Tools and the Role of Radioluminescence and Cherenkov Emission", Frontiers in Physics **8**, 328 (2020).

[3] L. A. Jarvis, R. Zhang, D. J. Gladstone, S. Jiang, W. Hitchcock, O. D. Friedman, A. K. Glaser, M. Jermyn, and B. W. Pogue, "Cherenkov Video Imaging Allows for the First Visualization of Radiation Therapy in Real Time", International Journal of Radiation Oncology*Biology*Physics **89**, 615–622 (2014).

[4]É. Cloutier, L. Archambault, and L. Beaulieu, "Accurate dose measurements using Cherenkov emission polarization imaging", Medical Physics **49**, 5417–5422 (2022).

[5]É. Cloutier, L. Beaulieu, and L. Archambault, "Direct in-water radiation dose measurements using Cherenkov emission corrected signals from polarization imaging for a clinical radiotherapy application", Scientific Reports **12**, 9608 (2022).