



Internship in medical nuclear physics

Characterization and correction of optical artifacts in 3D scintillation dosimetry for proton beam scanning

Context

Radiotherapy is a major modality for cancer treatment where proton therapy offers a significant ballistic advantage over photon therapy, thanks to the dose deposition profile of protons. Among current proton delivery techniques, Pencil Beam Scanning (PBS) is one of the most advanced approaches, providing high flexibility and better dose conformation.

However, the increasing use of small and highly modulated pencil beams requires dedicated and accurate dosimetry tools for quality assurance (QA). In this context, a scintillator-based dosimetry system has been developed. It consists of a $10 \times 10 \times 10 \text{ cm}^3$ scintillating block, a mirror, and an ultra-fast camera. The scintillation light emitted by the irradiated volume is recorded from two orthogonal points of view, enabling the reconstruction of three-dimensional dose distributions [1].

While this system offers promising capabilities for volumetric dosimetry, the measured signal is affected by several physical and optical effects. A previous study identified multiple sources of artifacts, including lens vignetting, reflections at the scintillator boundaries, light diffusion within the scintillating material, and refraction at the scintillator–air interface [2]. In addition, the camera images can contain hot pixels, resulting from scattered radiation directly hitting the camera sensor. Another important effect is scintillation quenching, which leads to a non-linear relationship between the scintillation yield and the Linear Energy Transfer (LET) of the charged particles [3]. These effects are complex and depend strongly on both the beam energy and its position within the scintillator. Their accurate characterization and correction are therefore essential to obtain reliable and robust 3D dose reconstructions.

Objectives

The objective of this internship is to characterize the different artifacts affecting the optical measurement of proton pencil beams and to develop correction strategies to improve the accuracy of 3D dose reconstruction.

The study will rely on the comparison of previously acquired experimental images with images generated from simulated dose and scintillation distributions. The work will involve several complementary steps:

1. Simulation of proton pencil beams

Individual pencil beams will be simulated using the treatment planning system (TPS), for a range of beam energies and positions within the scintillator. The simulations will provide 3D dose distributions with a spatial resolution of approximately 1 mm in the three dimensions.

2. Calculation of LET and scintillation quenching

LET distributions will be computed using analytical methods or the TPS. Based on these LET maps, scintillation quenching effects will be modelled to convert the simulated 3D dose distribution into a physically realistic 3D scintillation distribution.



3. Modelling of the imaging system

A projection matrix of the experimental optical setup will be developed to calculate the projection of the 3D scintillation distribution corresponding to the camera images. The resulting synthetic images will reproduce, as closely as possible, the geometry and acquisition conditions of the experimental system, providing a direct basis for comparison with measured images.

4. Characterization and separation of optical artifacts

Experimental and simulated images will then be compared for different beam energies and positions. The analysis of differential projection images will be used to characterize the spatial dependence of the observed artifacts and to investigate their respective contributions, including:

- camera hot pixels;
- lens vignetting and spatial variations in detection efficiency;
- reflections at the scintillator boundaries;
- light diffusion and refraction effects;
- geometrical effects related to the imaging setup;

The objective will be to distinguish the different sources of discrepancies between the experimental and simulated measurements and to establish a quantitative model of the main systematic effects.

5. Development and evaluation of correction strategies

Finally, several strategies for correcting the identified artifacts will be investigated. Both conventional analytical corrections and machine-learning-based approaches will be considered. Their implementation will be investigated at different stages of the reconstruction pipeline, notably:

- directly at the image level, by correcting the camera projections;
- at the 3D scintillation level, before dose reconstruction;
- potentially within the 3D reconstruction process itself.

The different approaches will be evaluated in terms of their ability to improve the agreement between measured and reconstructed dose distributions, as well as their robustness with respect to beam energy and position.

Expected outcomes

The internship will lead to:

- a modelling framework linking proton dose, LET, scintillation and camera images;
- a quantitative characterization of the main optical and instrumental artifacts;
- an improved understanding of their dependence on beam energy and position;
- one or several correction strategies for improving the accuracy of the 3D dosimetry system;
- a quantitative assessment of the impact of these corrections on 3D dose reconstruction.

The project will involve medical physics, proton therapy, analytical modelling, image processing, inverse problems and potentially machine learning, providing a



multidisciplinary research experience at the interface between physics and computational methods.

Expected skills

The student should have an education background in medical physics with a good knowledge of radiation-matter interactions, radiotherapy and dosimetry. The candidate must thus have strong interest for data analysis and simulation, and will have to develop skill in image manipulation, programming and Monte Carlo simulations.

This work [leads to a PhD-thesis](#).

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