



PhD position in medical physics

Machine Learning-Based 3D Dose Reconstruction from Limited Scintillation Projections for Proton Therapy Dosimetry

Description:

Radiotherapy is an important modality in treatment cancer. In this domain, proton beams have ballistic superiority against photon beams. Among the existing delivery techniques, pencil beam scanning is one of the most modern ones and presents many advantages in terms of flexibility and dose conformation. Nevertheless, the use of pencil beams (PBs) still requires well adapted dosimetry tools for small irradiation fields quality assurance. To answer this issue, an innovative dosimetry system has been developed. It is based on a scintillating block of $10 \times 10 \times 10 \text{ cm}^3$, a mirror and an ultra-fast camera recording the scintillation from two orthogonal points of view to reconstruct 3-dimensional dose maps [1].

The recorded images require some extensive preprocessing to correct hot pixels caused by scattered radiation directly hitting the camera sensor, optical artifacts[2] and the scintillation quenching [3].

3D reconstruction usually relies on numerous projections, not achievable in dosimetry in radiotherapy and many reconstruction algorithms have been developed for imaging purpose. A reconstruction method based on only two projections and relying on the radial symmetry of PBs has been developed and showed good performances. Nevertheless, some steps of the preprocessing and the reconstruction algorithm are computing time consuming and the radial symmetry limits its application to PBs.

Different experimental setups and machine Learning (ML) methods will be studied in this PhD thesis to address these limitations.

In a first step, two different setups (the previous setup and one including an additional scintillator sheet) generating different scintillation projections will be simulated to study different reconstruction strategies.

These digital setups will be fed to a treatment planning system (TPS) to generate 3D and 2D dose distributions for the two different setups. In parallel, LET and quenching correction maps will be computed to convert the dose distributions into scintillation distributions.

A projection matrix corresponding to the studied setups will allow to convert the 3D and 2D scintillation distributions into projection images and optical artifacts and noise (characterized in a preliminary M2 internship) will be added create a realistic images database.

The collection of 3D dose distribution and corresponding computed images will constitute the database used to study and evaluate different ML strategies for 3D dose reconstruction. The implemented reconstruction methods will be evaluated with experimental measurements performed at the Cyclhad proton therapy center, compared to conventional reconstruction methods and confronted to other beams such as not circular photon beams.

Context

Radiotherapy is a major modality in cancer treatment. Among the different radiation modalities, proton therapy offers significant ballistic advantages over conventional photon therapy due to the characteristic depth-dose distribution of proton beams. Pencil Beam Scanning (PBS) is one of the most advanced proton beam delivery techniques and provides high flexibility and excellent dose conformity. However, the use of small and highly conformal proton fields requires accurate and efficient dosimetry tools for treatment quality assurance.

To address this challenge, an innovative three-dimensional dosimetry system has been developed. The system consists of a $10 \times 10 \times 10 \text{ cm}^3$ scintillating volume, a mirror, and an ultra-fast camera recording scintillation light from two orthogonal views. These measurements are used to reconstruct three-dimensional dose distributions [1].



However, the recorded images require extensive preprocessing. In particular, corrections are necessary to compensate for hot pixels caused by scattered radiation directly interacting with the camera sensor, multiple optical artefacts [2], and scintillation quenching effects [3].

Furthermore, conventional three-dimensional tomographic reconstruction generally relies on a large number of projections, which is not compatible with real-time or routine dosimetry applications in radiotherapy.

A reconstruction method relying on only two projections and exploiting the radial symmetry of pencil beams has previously been developed and demonstrated promising performance. Nevertheless, several preprocessing and reconstruction steps remain computationally demanding. In addition, the assumption of radial symmetry restricts the applicability of the method to circular pencil beams and prevents its extension to more complex irradiation fields. The objective of this PhD thesis is therefore to investigate new experimental configurations and Machine Learning (ML)-based approaches to overcome these limitations and enable fast, accurate, and more general three-dimensional dose reconstruction.

Objectives

The first stage of the project will focus on the simulation and comparison of two experimental configurations: the existing dosimetry system and an alternative setup incorporating an additional scintillating sheet. These configurations will generate different scintillation projections and will allow the investigation of various reconstruction strategies.

For each configuration, a Treatment Planning System (TPS) will be used to generate three-dimensional dose distributions corresponding to realistic irradiation conditions. In parallel, Linear Energy Transfer (LET) distributions and quenching correction maps will be calculated in order to convert the physical dose distributions into corresponding scintillation light distributions.

Projection matrices describing the optical geometry of the different experimental setups will then be used to transform the simulated three-dimensional and two-dimensional scintillation distributions into synthetic camera images. Optical artefacts and noise characteristics, previously investigated during a preliminary Master's internship, will be incorporated into the simulations in order to generate a realistic and representative image database.

The resulting database, consisting of simulated dose distributions and their corresponding scintillation projections, will be used to train, optimize, and evaluate different Machine Learning strategies for three-dimensional dose reconstruction.

Several ML architectures and reconstruction approaches will be investigated with the objective of improving reconstruction accuracy, reducing computational time, and relaxing the assumptions required by conventional reconstruction algorithms.

Finally, the developed methods will be experimentally validated using measurements performed at the Cyclhad proton therapy centre. Their performance will be compared with existing conventional reconstruction techniques and evaluated for increasingly complex irradiation conditions, including non-circular fields and photon beams.

Expected Outcomes

This PhD project aims to develop a new generation of fast and accurate three-dimensional dosimetry methods for radiotherapy quality assurance. By combining realistic numerical simulations, innovative detector configurations, and Machine Learning-based reconstruction techniques, the project seeks to overcome the limitations of current two-view reconstruction approaches.

The expected developments could extend the applicability of scintillation-based three-dimensional dosimetry beyond individual proton pencil beams to more complex irradiation fields and potentially to other radiation modalities. Such advances could contribute to improving quality assurance procedures in modern proton therapy and radiotherapy.



Expected skills:

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

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