http://www.creatis.insa-lyon.fr

PhD proposal – CREATIS-IPNL

Towards real-time treatment control in protontherapy using prompt-radiation imaging: simulation and system optimization

http://www.creatis.insa-lyon.fr/site/fr/node/43926

Context

This phd proposal is within the project "Labex Primes[1]", in the WP5 "modelling and simulation" and 1 "innovative methods and instrumentation for radiation therapy". It is a collaboration between the laboratories CREATIS (team 4 "Tomoradio") and IPNL (team "Cas-Phabio").

Scientific background

Protontherapy is an emerging cancer treatment method that consists in irradiating tumours with proton beams. Although the proton ballistics, thanks to the Bragg peak, allows delivering high dose to the tumours while limiting the energy deposited in the healthy surrounding tissues [1], uncertainties remain in the proton range [2] and clinicians generally avoid direct exposure of organs at risk behind the Bragg peak.

Recently, prompt gamma-ray (PG) monitoring is being studied to overcome these limitations. PG are photons created by nuclear fragmentation of the target nuclei. Contrary to the gamma photons used in positron emission tomography (PET), PG are emitted almost instantaneously and cover a broad energy spectrum (up to more than 10 MeV). The works lead by the Lyon Nuclear Physics Institute (IPNL) and the IBA company (with which we collaborate) has shown that the PG depth profile can be measured with dedicated collimated gamma-cameras and give information on the position of the dose distal fall-off with an accuracy in the millimetre range, on a spot-by-spot basis [3], [4].

Monte-Carlo simulation is a key tool for studying such combined imaging and radiation processes. We recently proposed a method for modelling scanned proton beam delivery systems, which does not require any simulation of the treatment nozzle. It is based exclusively on the beam data library (BDL) measurements required for TPS [5]. Validations were performed against measured data and showed excellent agreement even in complex configurations. Based on this work, we extended GATE [6] to benchmark dose distributions in clinical configurations against the commercial XiO TPS (Elekta) [7].

Objectives

The goal of the thesis is (*i*) to investigate how to take full advantage of the information given by prompt radiation cameras and (*ii*) to optimize the camera design and acquisition protocol in clinical conditions. It will allow to provide recommendations for clinical usage of prompt radiation monitoring systems.

Method

We propose to study the response of the prompt radiation cameras currently designed in the collaboration in the case of real treatment plans, in order to determine appropriate criteria to stop the treatment in case of deviations exceeding the treatment error margins. This will be studied with Monte-Carlo simulations performed with the GATE/Geant4 platform [6].

Currently, the typical usage scenario of prompt radiation monitoring systems relies only on the distance between the dose fall-off and the prompt radiation fall-off [8]. However, it can only potentially detect Bragg peak offsets along the in-beam direction and is not necessarily robust to other types of discrepancies between planned and delivered dose distributions. The quantitative detection power of prompt radiation systems is largely unknown and is probably different according to each treatment field.

A task in this thesis will be to define and generate representative sets of abnormal situations (typically, patient mis-positionning, calibration errors) in order to study the relationship between delivered dose and monitored prompt radiation. Machine learning approaches may be used to "learn" this relationship and to propose

[1] PRIMES : Physique, Radiobiologie, Imagerie Médicale et Simulation

mathematical operators, called classifiers, specific for given treatment configurations. Once defined, the classifiers would then be used during an irradiation to detect potential irradiation problems. One important results of this approach will be to provide insights and recommendations to improve and optimise the design of the developed prompt radiation camera. The design of the camera will thus evolve during the thesis and the simulations will hence be adapted.

At the end of the project, we should be able to provide insights and recommendations for clinical usage of prompt radiation monitoring systems.

Misc

- **Skills.** Required: medical physics, Monte-Carlo simulations, C++. Skills in machine learning approaches will be appreciated.
- **Location**: CREATIS laboratory, in the Léon Bérard cancer centre, Lyon, France
- **Duration**: 3 years from September 2013
- **Contact** : send CV and letters by email to

- David Sarrut david.sarrut@creatis.insa-lyon.fr +33 (0) 4 78 78 51 51
- Etienne Testa testa@ipnl.in2p3.fr

[1] A. R. Smith, "Vision 20/20: Proton therapy," *Medical Physics*, vol. 36, no. 2, p. 556, 2009.

[2] P. Andreo, "On the clinical spatial resolution achievable with protons and heavier charged particle radiotherapy beams.," *Physics in medicine and biology*, vol. 54, no. 11, pp. N205–15, Jun. 2009.

[3] M. Testa, M. Bajard, M. Chevallier, D. Dauvergne, N. Freud, P. Henriquet, S. Karkar, F. Le Foulher, J. M. Létang, R. Plescak, C. Ray, M.-H. Richard, D. Schardt, and E. Testa, "Real-time monitoring of the Bragg-peak position in ion therapy by means of single photon detection," *Radiat. Environ. Biophys.*, vol. 49, p. 337-343, 2010.

[4] F. Roellinghoff, M.-H. Richard, M. Chevallier, J. Constanzo, D. Dauvergne, N. Freud, P. Henriquet, F. Le Foulher, J. M. Létang, G. Montarou, C. Ray, E. Testa, M. Testa, and A. H. Walenta, "Design of a Compton camera for 3D prompt- imaging during ion beam therapy," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 648, pp. S20–S23, Aug. 2011.

[5] L. Grevillot, D. Bertrand, F. Dessy, N. Freud, and D. Sarrut, "A Monte Carlo pencil beam scanning model for proton treatment plan simulation using GATE/GEANT4," *Physics in Medicine and Biology*, vol. 56, no. 16, pp. 5203–5219, Aug. 2011.

[6] S. Jan, D. Benoit, E. Becheva, T. Carlier, F. Cassol, P. Descourt, T. Frisson, L. Grevillot, L. Guigues, L. Maigne, C. Morel, Y. Perrot, N. Rehfeld, D. Sarrut, D. R. Schaart, S. Stute, U. Pietrzyk, D. Visvikis, N. Zahra, and I. Buvat, "GATE V6: a major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy.," *Physics in medicine and biology*, vol. 56, no. 4, pp. 881–901, Jan. 2011.

[7] L. Grevillot, D. Bertrand, F. Dessy, N. Freud, and D. Sarrut, "GATE as a GEANT4-based Monte Carlo platform for the evaluation of proton pencil beam scanning treatment plans.," *Physics in medicine and biology*, vol. 57, no. 13, pp. 4223–44, Jul. 2012.

[8] M. Moteabbed, S. Espana, and H. Paganetti, "Monte Carlo patient study on the comparison of prompt gamma and PET imaging for range verification in proton therapy.," *Physics in medicine and biology*, vol. 56, no. 4, pp. 1063–82, Feb. 2011.