Master thesis on ion imaging

The Chair of Experimental Physics – Medical Physics in the Faculty for Physics of the *Ludwig-Maximilians-Universität München* (LMU Munich) is offering two positions for Master students to join the *Deutsche Forschungsgemeinschaft* (DFG) project “Hybrid ImaGing framework in Hadrontherapy for Adaptive Radiation Therapy (High-ART)” (https://www.med.physik.uni-muenchen.de/research/image-guidance/proton-ion-ct/index.html).

Title (1)

Machine learning in ion imaging (radiography)

Background

In ion beam therapy ion radiographies are typically investigated with the purpose of adjustment of the X-ray image for treatment planning and/or verification of the treatment delivery in order to overcome the inaccuracy of the empirical calibration of the X-ray image [1] (**Figure 1**). In particular, the adjustment of the X-ray image is based on the numerical optimization of the matching between the ion radiography and the numerically modeled radiography of the adjusted X-ray image [2]. The adjustment relies on the hypothesis of bijective function mapping the gray levels of ion image to the gray levels of the X-ray image (joint histogram). However, the adjustment of the X-ray image can be impaired by inter-fractional anatomical changes affecting the co-registration between the treatment planning and delivery scenarios. Prior the adjustment, the X-ray image should be therefore adapted to the treatment delivery scenario.

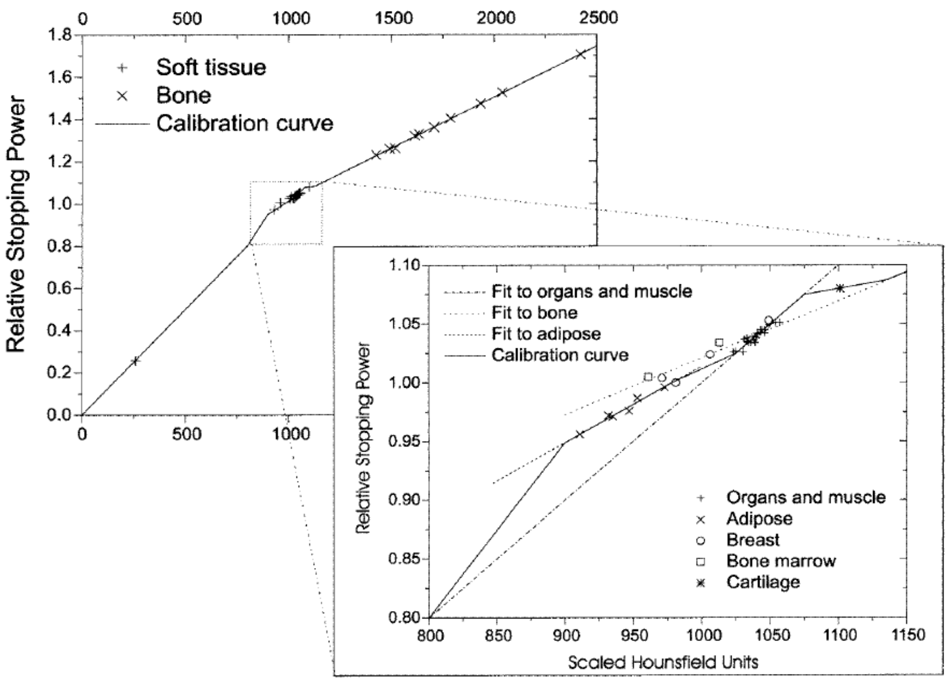

Figure 1. Empirical calibration of the X-ray image for treatment planning [1].

Task

As an alternative, the adjustment could be based on an in-room image directly representative of the treatment delivery scenario to enable treatment planning adaptation prior treatment delivery. Typically, X-ray imaging (Cone Beam Computed Tomography, CBCT) or MRI (Magnetic Resonance Imaging) systems are mounted into the treatment room for patient positioning and image guidance. However, these imaging modalities compromise the bijective feature of the joint histogram. The thesis focuses on the adjustment of the in-room image considering that the joint histogram can be a non injective function (gray level of the in-room image can correspond to multiple gray levels of the ion image) and even not a function (gray level of the ion image can correspond to multiple gray levels of the in-room image).

The thesis aims at solving this mapping by means of algorithms of machine learning combined with the numerical optimization for the adjustment of the in-room image. Training data are derived from analytical phantoms for different imaging modalities as well as from Monte Carlo simulations based on clinical datasets, relying on the established collaboration with the *Klinikum der Ludwig-Maximilians-Universität München* for the availability of CBCT images and MRI.

[1] Schaffner, B., & Pedroni, E. (1998). The precision of proton range calculations in proton radiotherapy treatment planning: experimental verification of the relation between CT-HU and proton stopping power. *Physics in Medicine & Biology*, *43*(6), 1579.
[2] Schneider, U., Pemler, P., Besserer, J., Pedroni, E., Lomax, A., & Kaser-Hotz, B. (2005). Patient specific optimization of the relation between CT-Hounsfield units and proton stopping power with proton radiography. *Medical physics*,*32*(1), 195-199.

Requirements

Academic records are requested for application. Knowledge of basic programming languages for imaging (python, Matlab, c++) is desired. The novelty of the thesis calls for creative attitude and dedicated passion in programming.

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Title (2)

Tomographic image reconstruction in ion imaging

Background

In ion beam therapy the tomographic image reconstruction of ion radiographies aims at replacing the X-ray image for treatment planning and/or verification of the treatment delivery in order to overcome the inaccuracy of the empirical calibration of the X-ray image [1]. Constraints in clinical translation of typical detector prototypes based on single particle tracking (list-mode detector configuration) have promoted the development of integration-mode detector configuration, measuring the stopping power of the pencil beam as a Bragg peak signal obtained by discretizing the total absorption detector into a stack of absorbers interleaved by detectors (channels) (**Figure 2**) [3]. A tomographic image reconstruction algorithm dedicated to integration-mode detector configuration has been proposed and preliminary investigated with anthropomorphic analytical phantoms [4]. The algorithm makes use of the measurement of stopping power and the model of the scattering power for each channel of the detector. The preliminary investigation has shown the potential of the proposed algorithm to provide better image quality than conventional tomographic image reconstruction (**Figure 3**).

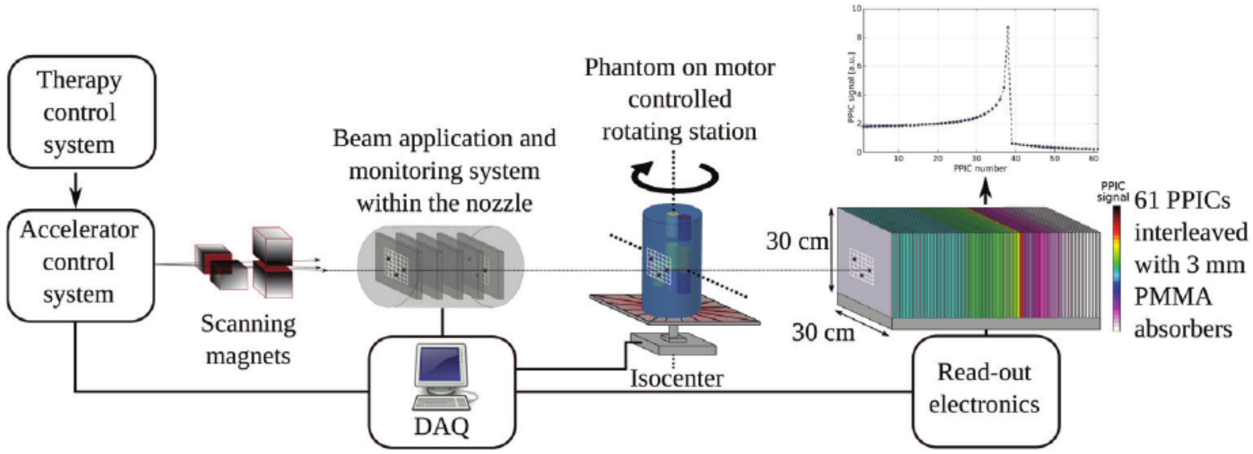

Figure 2. Integration-mode detector configuration [3].

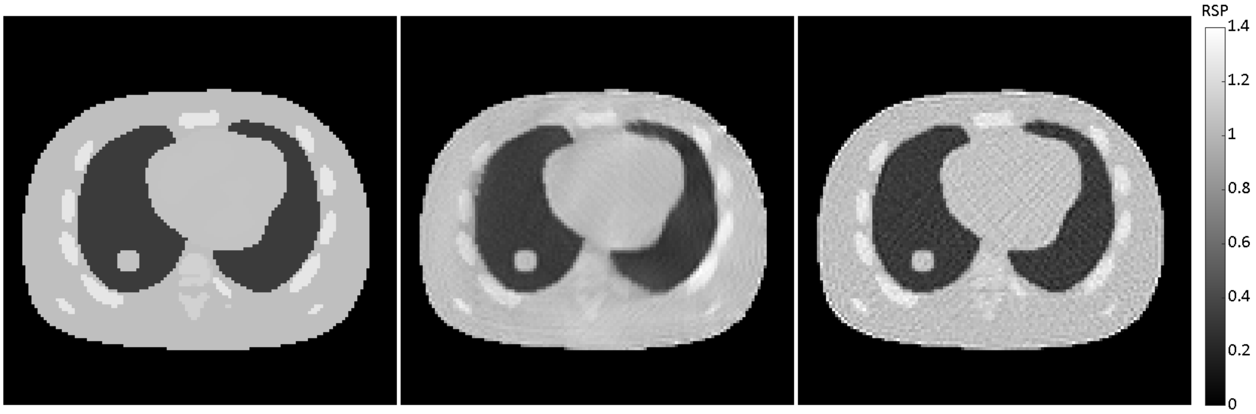

Figure 3. The anthropomorphic analytical phantom, the dedicated tomographic image reconstruction algorithm and conventional tomographic image reconstruction [4].

Task

The thesis aims at further investigating the tomographic image reconstruction algorithm dedicated to integration-mode detector configuration with Monte Carlo simulations based on clinical datasets, thus complementing the investigation with anthropomorphic analytical phantoms. Particularly, the comparison should be also extended to tomographic image reconstruction for list-mode detector configuration. This implies the handling of Monte Carlo simulations based on clinical datasets (relying on the established collaboration with the *Klinikum der Ludwig-Maximilians-Universität München* for the availability of X-ray images for treatment planning) as well as Multiple Coulomb Scattering models embedded in the state-of-the-art Maximum Likely Path algorithm for trajectory estimation in single particle tracking.

[3] Meyer, S., Gianoli, C., Magallanes, L., Kopp, B., Tessonnier, T., Landry, G., ... & Parodi, K. (2017). Comparative Monte Carlo study on the performance of integration-and list-mode detector configurations for carbon ion computed tomography. *Physics in Medicine & Biology*, *62*(3), 1096
[4] C. Seller Oria, S. Meyer, E. De Bernardi, K. Parodi and C. Gianoli. A Dedicated Tomographic Image Reconstruction Algorithm for Integration-Mode Detector Configuration in Ion Imaging. *In Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2018 IEEE.*

Requirements

Academic records are requested for application. Knowledge of basic programming languages for imaging (python, Matlab, c++) and Monte Carlo simulations is desired.

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