Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Project Title: Uncertainty of AI-based dose prediction compared to Monte Carlo methods

Type: Postdoc or PhD

Principal Investigators

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Background

AI-based methods are increasingly used in radiotherapy with a prospect of enabling real-time calculations of dose distributions for adaptive treatment planning [1]. Different from the already more advanced AI-based dosimetry calculations in imaging, treatment planning requires much lower uncertainties on the few percent level. Similar to AI applications in imaging, synthetic reference data sets produced by Monte Carlo simulations will play an important role for training, testing and validating the AI algorithms as systematic discrepancies introduced in data pooling ("center effects", e.g. due to different protocols for data collection and reporting) are absent. In order to simulate at a rate of several thousand reference data sets within a few months, application of special numerical tricks for variance reduction is indispensable that generally require a lot of expertise for their proper application. Many radiation transport codes include respective features that may produce biased results. Such bias on training data as well as the uncertainties of simulation results may introduce another uncertainty component with the predictions of the trained AI algorithms (in addition to those originating in the algorithms themselves). The ground work for establishing uncertainty budgets of radiation transport Monte Carlo simulations has been done in two preceding PhD projects and in code intercomparison exercises in the frame of EURADOS WG 6 Computational Dosimetry [2], [3], [4]. A systematic general framework for establishing uncertainty budgets for Monte Carlo simulations is still to be developed as well as an assessment of the impact of these uncertainties on the predictions of AI algorithms trained by such simulation results.

Project Aim, Objectives and Program

Investigation of the influence of bias and uncertainty in synthetic data sets used for training a neural network on the prediction capabilities of the network for a showcase example from radiotherapy or radiation protection in medicine.

- Investigation of the suitability of different approaches to include uncertainty propagation in Monte Carlo simulations of radiation transport in medical applications.
- Establishment of an uncertainty budget for synthetic reference data sets produced using Monte Carlo simulations.
- Evaluation of the impact of the resulting uncertainties on the uncertainties of AI algorithm-based dose predictions.

Work program:

- Identification of the optimum showcase examples in discussion with EURADOS WGs and (pre-)clinical partners. Examples could be dose distribution in the whole body in a radiotherapy treatment.
- Investigation of possibilities for implementing techniques for uncertainty propagation (e.g. deterministic sampling, sensitivity analysis, …) in Monte Carlo radiation transport simulations
- Development of a detailed Monte Carlo simulation for the showcase. with a radiation transport code implementing the error propagation and variance reduction techniques
- Production of a sufficiently large set of synthetic reference data and training of a neural network or other machine learning algorithm with the set of simulation input data and simulation predictions.
- Assessment of the uncertainties of the reference data and of the resulting uncertainty of the AI-based prediction.
- Investigation of methods for correcting variance-reduction related bias and assessing the uncertainty of the correction.

Available data

- not applicable, they will be produced in the course of the project

Collaboration

- Technische Universität Berlin
- EURADOS WG 6 Computational Dosimetry, WG 9 Radiation dosimetry in radiotherapy, WG 12 Dosimetry in medical imaging and potential new WG on dosimetry in nuclear medicine
- University of Heidelberg and University of Essen
- MIT/Harvard University

Candidate Requirements

- MSc in computer science, mathematics, physics or similar
- Good programming skills and understanding of computer science
- Experience in radiation transport simulations is an asset

References

[1] Vandewinckele L et al. Overview of artificial intelligence-based applications in radiotherapy: Recommendations for implementation and quality assurance.. Radiotherapy and oncology : journal of the European Society for Therapeutic Radiology and Oncology 153, 55–66 (2020)

[2] Villagrasa C et al. Assessing the contribution of cross-sections to the uncertainty of Monte Carlo calculations in micro- and nanodosimetry. Radiation Protection Dosimetry 183, 11-16 (2019)

[3] Caccia B et al. 2020. A model validation scheme for Monte Carlo simulations of a medical linear accelerator: geometrical description and dosimetric data used in the “Linac Action”. EURADOS Report 2020-05. European Radiation Dosimetry Group e. V., Neuherberg.

[4] Rabus H et al. Quality Assurance for the Use of Computational Methods in Dosimetry: Activities of EURADOS Working Group 6 “Computational Dosimetry”. J Radiol Prot in press, doi: 10.1088/1361-6498/abd914 (2021)