Novel Treatment Planning Projects

1. Texture analysis for Normal Tissue Complication Modelling in Radiotherapy (MEP);
2. Adjoint methodologies for proton therapy (BEP,MEP);
3. Probabilistic treatment planning for proton therapy (MEP).

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1.Texture analysis for Normal Tissue Complication Modelling in Radiotherapy (MEP)

Radiotherapy heavily relies on a variety of medical imaging modalities (CT, MRI, PET), that help in the diagnosis, prognosis and follow up of cancer patients. In the evaluation of the obtained images, Texture Analysis (TA) is an emerging field that can provide information based on the grey values in image voxels. TA encompasses a collection of methods under the umbrella of machine learning and big data approaches, that quantify certain aspects of images that are either indiscernible by human eye or can only be described in vague terms (such as smoothness or graininess). The main advantages of TA is that it can provide otherwise unavailable quantitative features of images that can be correlated with specific metrics of interest. For example, TA could detect tumor heterogeneity based on CT images, which in turn is prognostic of treatment response, thus could potentially help making better decisions regarding the best course of action for a given patient.
So far Texture Analysis has been exclusively used for evaltion medical images. The novel idea of using TA on dose distributions, with the aim of deriving Normal Tissue Complication Probability (NTCP) models that surpass currently available ones, has just be proposed by our Erasmus MC - TU Delft collaboration group. Normal tissue complications are the main limitation in increasing therapeutic doses, thus are the primary causes for radiotherapy treatment failure. Since NTCP models quantify the response of healthy organs to the received dose, their accurate knowledge could enable increasing doses and improving outcomes. The focus of this project is to explore such NTCP models and how they could be incorporated in the treatment planning workflow itself, representing a major, paradigm shifting step towards the future of radiotherapy.

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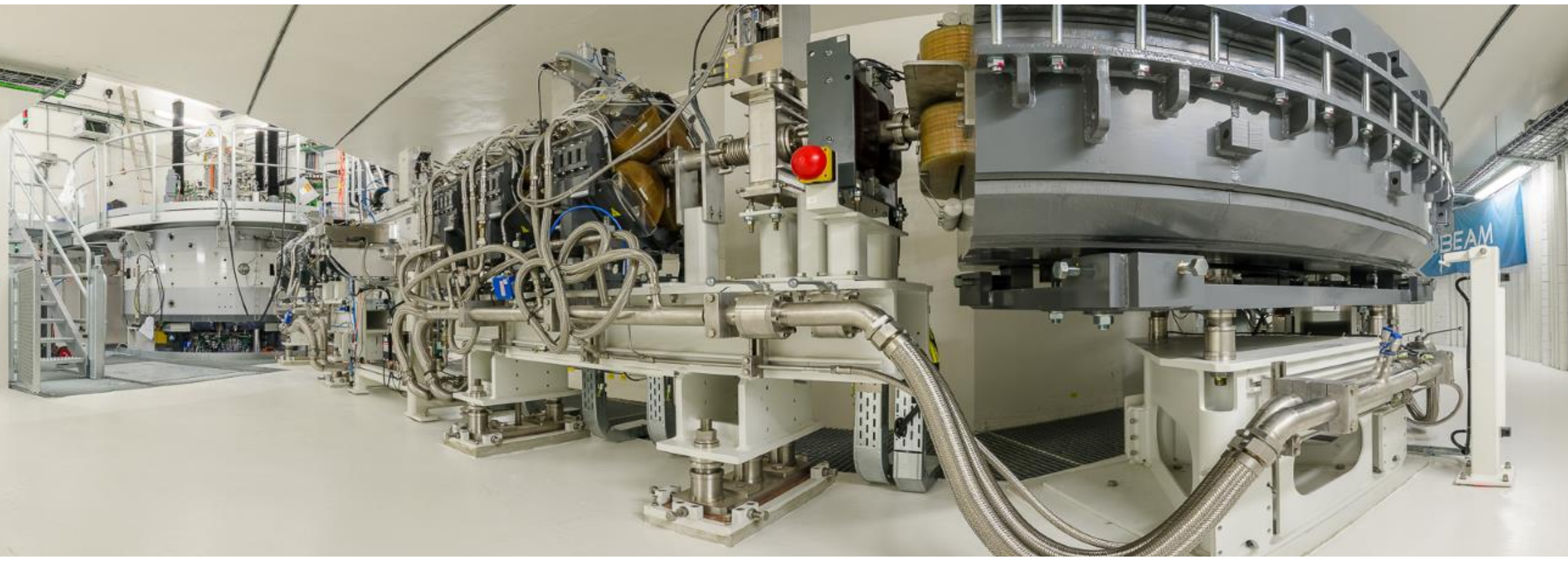

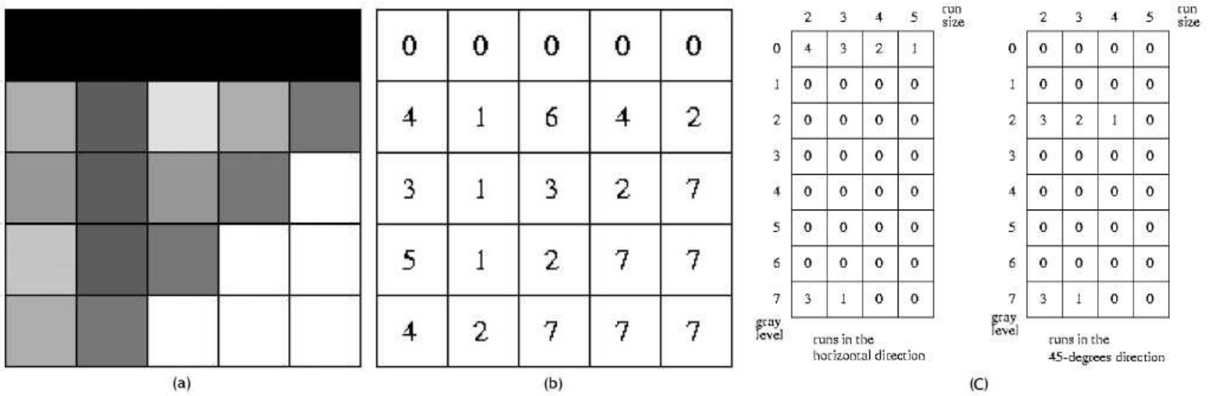

Figure 1 - Texture analysis of an example image (a), represented by the gray values (b). (c) shows two possible TA features, the run-length matrices in horizontal and 45 degree directions showing the occurrence frequencies of different intensities.

2.Adjoint methodologies for proton therapy (BEP,MEP)

Proton therapy is novel form of radiotherapy for treating cancer patients, that has the ability to better protect healthy organs than conventionally used photons. However, the higher dose conformity of protons comes at the cost of increased sensitivity to uncertainties in patient anatomy, positioning, or proton energy. Thus, it is important to know what the exact dosimetric effects of these uncertainties are and how to make proton therapy plans robust against them. Typically, this is done by re-evaluating plans in different possible error scenarios according to Monte Carlo sampling, or using some form of meta-modelling approach (such as Polynomial Chaos Expansion).

The goal of this project is to investigate the potential of a fundamentally different methodology based on adjoint theory. The huge advantage of adjoint methods is that for linear problems (such as proton transport in the patient) they can provide computationally very efficient calculation of the sensitivities of responses of interest to all input parameters (i.e. all sources of uncertainties). Thus, they hold the promise of much more accurate, quantitative and fast evaluation of the effects of errors, as well the key for their effective handling. While adjoints have been used extensively in neutron transport applications, they are completely new to the field of proton therapy. Hence the project is a very interesting, new research topic in a mathematically challenging, complex, but high impact field, where the student has a lot of freedom defining his/her own directions, as well as a high potential to reach significant and truly novel scientific results.

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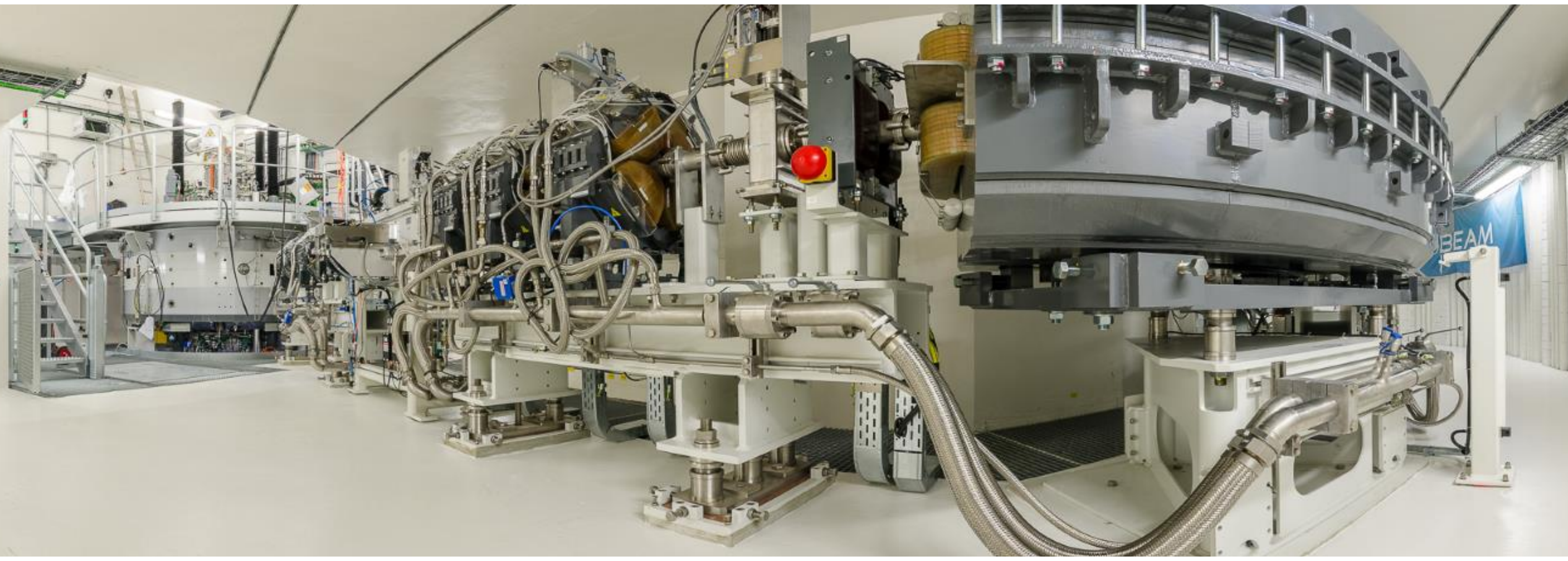

3.Probabilistic treatment planning for proton therapy (MEP)

Proton therapy treatment planning is a complicated, computationally intensive procedure. It focuses on providing patients with personalized treatments that deliver high prescribed doses to target structures (tumors), while spare healthy organs as much as possible, which is achieved by choosing the optimal beam angles, proton energies and proton pencil beam intensities. Typically, beam angles are chosen manually by the treatment planners based on previous experience, whereas choosing the proton energies and pencil beam intensities leads to a large scale convex optimization problem (there are millions of voxels in the patient, with thousands of available pencil beams whose intensities need to be optimized).

Conventional treatment planning only includes the nominal scenario, meaning that it is supposed that the anatomy of the patient is exactly identical on each day of the actual treatment. Since in reality this is clearly not true, and proton therapy is very sensitive to all sources of uncertainties (such as an error in the daily patient positioning, or the internal movement of organs between days), it is important to take into account such errors and their dosimetric effect. The goal of this project is to develop methods for probabilistic optimization, such as the errors scenarios can be included in treatment planning together with their occurrence probability. This would enable planning treatments that are robust against uncertainties (ensuring treatment success), are not over-conservative (minimizing normal tissue doses), and at the same time quantitatively takes into account errors and their effects. The research includes investigating and developing different probabilistic optimization approaches (such as expected value optimization or value-at-risk/conditional-value-at-risk optimization), testing the different methodologies on model cases as well as directly on real patient data, and implementing the developed techniques in the clinical treatment planning software to ensure the most realistic and accurate evaluation against current protocols.

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