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Recent developments of helium-beam radiography (αRAD) aiming at image guidance in ion-beam therapy

Ion-beam therapy can offer advantages over the standard radiotherapy with photons, especially for cancer treatments where organs at risk are in close proximity to the tumor to be treated. These advantages mainly result from the characteristic of delivering highly focused doses to the tumor. However, this potential can sometimes not be fully used in clinics, since the focused dose distribution is connected to a higher sensitivity to uncertainties. Uncertainties can, e.g., arise from anatomical changes—such as cavity fillings, weight loss or tumor regression—that might go unnoticed during the course of the therapy.
In this context, we consider ion-beam radiography a very promising transmission imaging modality, since it could detect and quantify these potential anatomical changes on a daily basis. The verification of therapy could be performed directly before each treatment fraction in the treatment room at low imaging doses of ˜100 µGy per radiograph.
We have been investigating this imaging modality since 2015 using our unique and compact detection system [1] of six thin (˜400 µm) silicon pixel Timepix detectors [2] for helium-beam radiography (αRAD). It contains a pair of trackers for measuring each helium-ion path in front and behind the imaged object.

An obstacle that remained until recently was that a 2D ion radiograph¬—a projection along the beam direction¬—could not provide the information whether an anatomical change was in the treatment beam path (i.e. of high relevance for the outcome of the therapy) or behind the tumor (irrelevant for the treatment accuracy). In this contribution we report on our development of an experimental method that is capable of providing depth information of anatomical changes from 2D helium-beam radiographs. This method is referred to as 2.5D imaging in the following.

2.5D imaging, which was recently also suggested in a Monte Carlo study [4], is investigated in experiments where simple geometrical objects and complex anthropomorphic phantoms were imaged before and after inserting a geometrical change that mimics an internal anatomical change. By reconstructing helium-beam radiographs at many different depths inside the object and deploying suitable metrics for spatial resolution assessment, the depth at which the change appears the sharpest was identified. The difference between this measured and the actual depth at which internal changes were introduced was defined as the accuracy of the method. It was determined to be smaller than 11 mm in both studied phantom types. Such a depth accuracy is sufficient for evaluating whether a detected anatomical change is of relevance for the subsequent treatment (i.e. in the treatment beam path).

Moreover, in a second recent study the accuracy of radiological thickness was assessed by comparing the measured helium-beam radiographs to projections of dual-energy CTs that were acquired with a commercially available CT scanner using clinical protocols. Dual-energy CTs are currently considered as gold standard for measuring radiological thickness of complex human-like objects. The agreement between the two imaging modalities in terms of radiological thickness was better than 0.65 % (mean absolute percentage deviation) while the imaging dose of the helium-beam radiograph and the dual-energy CT was estimated to be 290 µGy and 23.8 mGy, respectively [3]. Figure 1 shows a comparison of the images obtained by αRAD and dual energy CT.

Overall, these promising results encourage next steps towards a clinical application in the future that are presented as outlook.

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Workshop topics

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