Integration of an optical tracking system for beam guidance in radiotherapy of moving targets using carbon ions*

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In the therapy pilot project from 1997 to 2008 over 400 patients with tumours in the head and neck region or in the prostate were treated at GSI with carbon ions. The aim of several research groups is to extend carbon ion therapy to moving targets such as lung tumours. Interplay of the scanned ion beam and tumour motion can lead to unacceptable dose profiles in the patient.

In order to compensate for tumour motion, several mitigation strategies have been developed and implemented at GSI. For applying the compensation it is vital to have an accurate observation of the target position over time.

In this study we present the implementation of an infrared based optical tracking system (OTS) and its experimental validation using an anthropomorphic breathing phantom in order to simulate the clinical workflow of a lung tumour treatment.

Methods and materials

Breathing phantom

A homemade breathing phantom was chosen for the treatment. It consists of PVC bones in the thorax region covered with rubber acting as patient skin. A string is attached to the chest wall which can be pulled with an electrical motor. This leads to a contraction of the phantom resulting in a breathing-like motion.

The phantom is filled with a PMMA block containing 20 pinpoint ionization chambers. This block serves as target and is moved in three-dimensions using an industrial robot arm synchronized with the thorax deformation. (A video is shown in [1])

Among the motion compensation techniques implemented at GSI, beam tracking was chosen for the experiment. In this approach, the scanner magnets are used to steer the ions following the target motion. The motion can also lead to ion range changes, for example when traversing rib bones. To compensate for the changes in range a double wedge system is employed to adjust the amount of material in front of the target. [2]

Motion detection

To fully exploit the potential of beam tracking the target position must be known with high-frequency and accuracy. Fluoroscopy represents a possible solution, but results in high additional dose to the patient. Therefore different approaches using external motion surrogates are investigated.

In this approach an infrared OTS was implemented in the treatment room of GSI. Several markers coated with a reflective surface are attached on the phantom surface. Three cameras and IR emitters capture the reflected light and thus determine the marker position. The target position is estimated from the marker signal using external-internal correlation models. The correlation models are based on the 4DCT taken for treatment planning.

Experimental setup

The breathing phantom was setup in the cave using the OTS cameras. The goal of the irradiation was to deliver 1 Gy dose in the target with carbon ions.

To assess the impact of the motion compensation, several irradiations were performed with different parameters. The motion was varied from a regular breathing to irregular breathing patterns with baseline shifts or phase shifts between thorax and target motion. The dose measured during motion was compared to a static reference case.

Results and conclusion

For the regular breathing, a mean dose difference of 0.8±3.7% (mean ± std. deviation) was measured for the pinpoint chambers relative to the static case when using correlation models. This represents a significant ($p<0.001$) improvement over the non-compensated irradiation where the difference was -13±25%. A significant improvement was also found when introducing baseline drifts (2.5±3.2%) or phase shifts (0.2±4.3%).

The experimental results show that beam tracking using an OTS for beam guidance is able to deliver the treatment in a clinical scenario with dose profiles that are comparable to a static case.

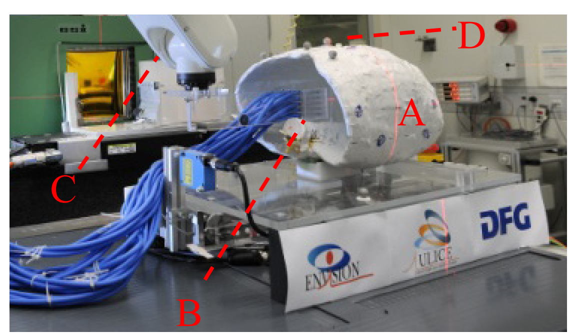

Figure 1: Breathing thorax (A), ion chambers (B), robotic arm (C), reflective markers (D). Picture by G.Otto, GSI

References

[1] http://www.youtube.com/watch?v=4QjsM2xUC3I
[2] Bert et al, Radiat. Oncol, 2010

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