Ion Beam Tracking using Ultrasound Motion Detection

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Motivation

In particle therapy of moving tumors, currently being implemented at several sites, beam scanning is the preferred option to conform the dose distribution to the target. This technique allows to follow the motion of e.g. a tumor in the lung via motion mitigation techniques [1]. Real-time knowledge of target position with mm precision is a requirement for these techniques. We investigated the feasibility of motion detection using ultrasound (US) at the heavy ion tumor treatment facility of GSI Darmstadt.

Materials and Methods

In our feasibility study (cf. Figure 1), a robotic arm (KUKA KR 5 sixx R850) generated various periodic two-dimensional trajectories in a plane perpendicular to the beam. A field of 3×3 cm^2 was homogenously irradiated with a E=200 MeV/u, FWHM=6 mm beam of calcium ions on radiosenstive films (Kodak X-Omat) using the beam tracking technique [1]. A US position measurement system (mediri GmbH, Heidelberg) was integrated into the GSI therapy control system. A rubber ball was used as tumor surrogate. Its position in water was continously measured by the US system with a sampling rate of about $\Delta t = 35$ ms. The films were attached to the robot arm and thus moved with the rubber ball. Position reconstruction from US and data communication introduced a delay of $D = 70 - 80$ ms until irradiation, resulting in a deviation of up to about 5 mm. We compensated this delay using an artificial neural network (ANN). ANNs are non-linear computational models which can be used to predict the evolution of a discrete time-series from previous values [2]. We performed several measurement series with a moving and one with a static target (reference). For each motion axis we used the trajecory $A \cdot \sin^{2n}(\frac{2\pi}{T}t)$ with $n = 1, 2, 4$, $T = 3$ s and $A = 10$ mm. We have chosen these trajectories as they are known to model diaphragm motion due to breathing [3].

Results and Conclusions

Figure 2 proofs that we could produce homogenous irradiation patterns with mm precision if ANN prediction was used. In order to quantify the similarity to the static case, we computed three measures for each case: The average FWHM of the blackening was determined from four equidistant lines across each pattern in x and y direction. The inhomogeneity IH $= \sigma / G$ of the blackening is given by the standard deviation σ of the grey values divided by average G around the center of each pattern. Our feasibility study has successfully shown that ion beam tracking using US motion detection is feasible. It could be a dose-free alternative to X-ray based motion detection techniques and would not depend on implanted markers. US allows to track target motion directly. No correlation model between the actual internal anatomy (determined via 4DCT) and an external motion surrogate (e.g. moving patient surface) has to be implemented.

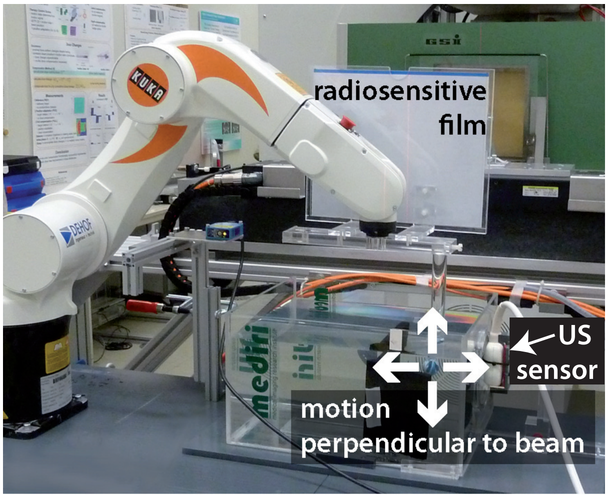


Figure 1: Experimental setup in cave M at GSI.

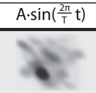
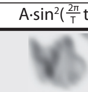
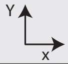
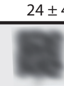
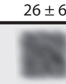
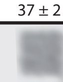
	static	$A \cdot \sin(\frac{2\pi}{T} t)$	$A \cdot \sin^2(\frac{2\pi}{T} t)$	$A \cdot \sin^4(\frac{2\pi}{T} t)$
without ANN				
IH (%) FWHM X (mm) FWHM Y (mm)	0.8 32.1 ± 0.1 32.5 ± 0.1	> 15 24 ± 5 24 ± 4	> 18 19 ± 10 26 ± 6	> 13 36 ± 2 37 ± 2
with ANN				
IH (%) FWHM X (mm) FWHM Y (mm)		5.5 33.5 ± 0.5 34.1 ± 0.5	6.3 33.1 ± 0.5 33.4 ± 0.5	3.5 31.3 ± 0.5 31.9 ± 0.5

Figure 2: Irradiated films. Top: Without ANN prediction. Bottom: With ANN prediction.

References

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