Influence of bone suppression on accuracy and robustness of tumor motion monitoring using intensity-based 2D/3D registration

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Objective

Precise dose deposition to tumors, while sparing organs at risk (OARs) is a big challenge in radiation oncology. Respiration induced tumor motion during irradiation can require extensive safety margins and therefore causes dose deposition to healthy tissue. Tumor motion monitoring is a method to reduce the uncertainty regarding the tumor location and therefore allows a reduction of the safety margins. To realize tumor motion monitoring in real-time, a software called FIRE[1,2], which makes use of an intensity-based 2D/3D registration algorithm, was developed at Medical University of Vienna. In clinical practice bone tissue shows up with a much higher contrast on the X-ray images compared to tumor tissue and lung tumors are often overlapping partially or even completely with ribs. Therefore, registration accuracy and robustness can be decreased significantly. The aim of this work is to propose a method for suppressing the bone tissue from the digitally reconstructed radiographs (DRR) and intra-fractional X-ray images to increase the accuracy and robustness of the registration algorithm.

Material and Methods

To enable subtraction of DRR image segments from the X-ray, the intensity characteristics of the X-ray image in relation to the DRR was evaluated with MATLAB. This step was realized by creating a joint-histogram for every pixel of the region of interest (ROI) followed by a 4th order polynomial fit to get an image intensity transfer function (ITF) as shown in Figure 1.

For suppression of the bone tissue within the X-ray images, a ray-casting of the CT volume considering bone tissue only due to thresholding of the corresponding Hounsfield unit range, was performed (DRR_BONE). This image was transformed with the ITF to match the characteristics of the X-ray image. The following subtraction from the original X-ray (XRAY) image led to a bone suppressed image (XRAY_BS) as shown in Figure 2.

For evaluating accuracy and robustness improvements, tumor registration in FIRE was done for a 6 cm cranio-caudal tumor motion with the ARDOS[3] breathing phantom. Three different merit-functions like stochastic rank correlation (SRC), cross correlation (CC) and mutual information (MI) were used for testing 3 different scenarios:

1) CT Volume and X-rays without ribs as a ground truth scenario
2) CT volume and X-rays with ribs but without bone suppression
3) CT volume rendered without ribs and X-rays with bone suppression

For scenario 3 the mean average error (MAE), root mean square error (RMSE), min and max error was calculated with respect to scenario 1.

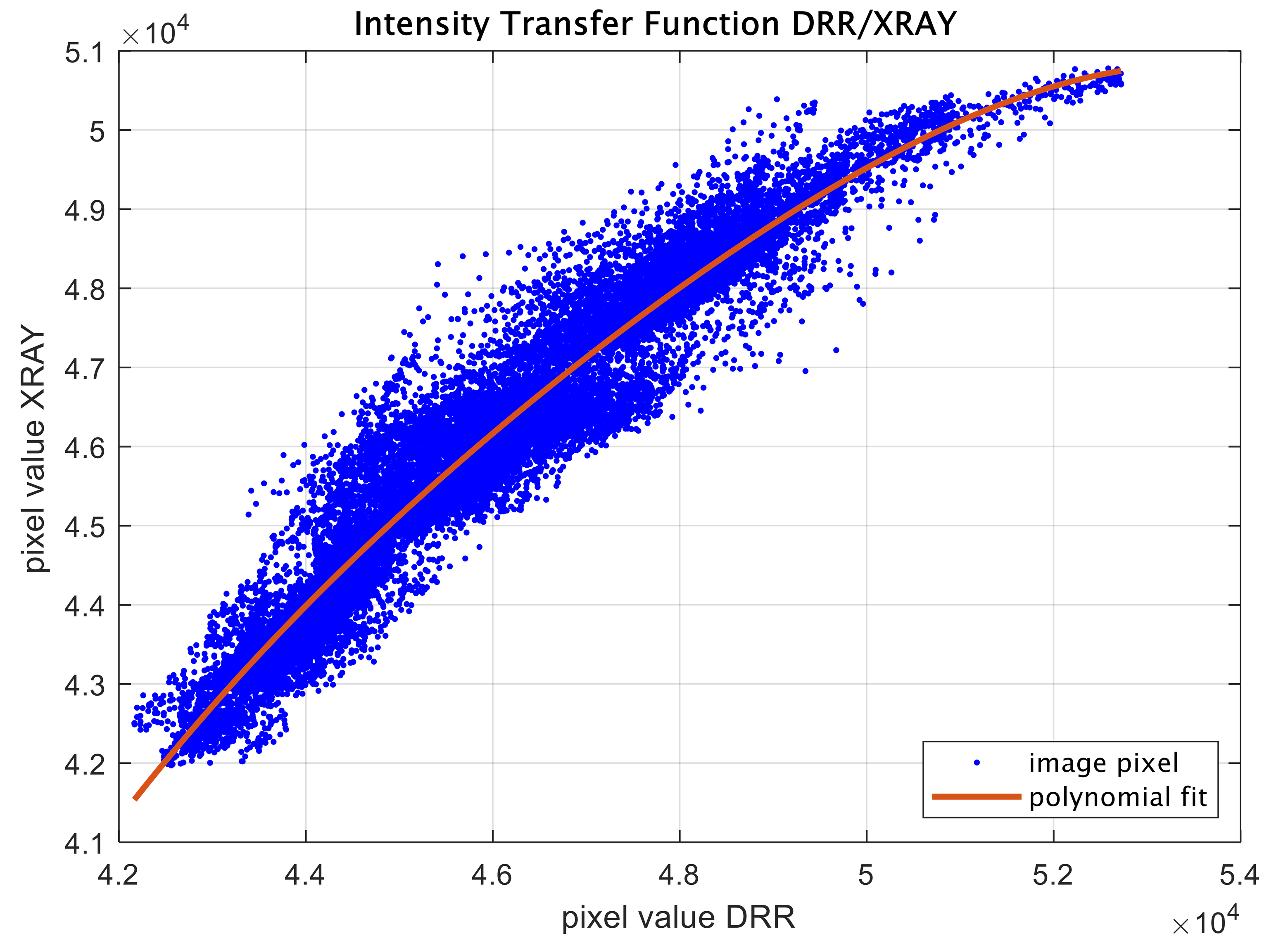

Figure 1: Correlation of pixel intensities of DRR and X-ray image (blue) and intensity transfer function established by a 4th order polynomial fit (red)

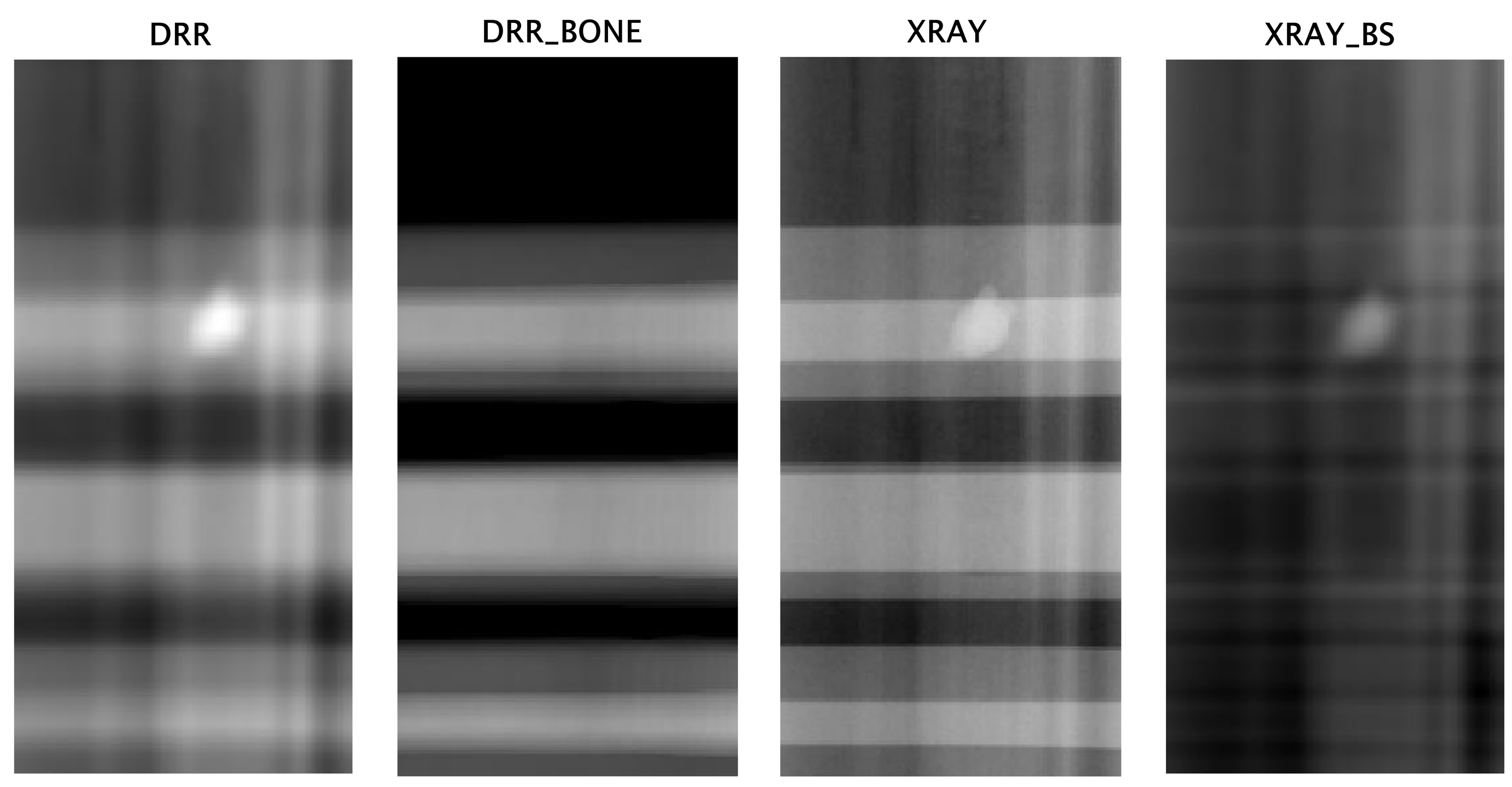

Figure 2: ROI of DRR including ribs and tumor, DRR of bone tissue only, X-ray image and the final bone suppressed X-ray image

Results

The resulting vertical intensity line profiles across the tumor of the bone suppressed X-ray image shows a reduction of intensity within bone compartments compared to the original X-ray image as shown in Figure 3 (red and blue line). In scenario 2 the tumor registration failed for all merit functions since the image signal of the bone tissue was predominant with respect to the tumor. In scenario 3 the registration was performed successful and the resulting errors are given in Table 1. Since SRC is intrinsically based on correlation the results were identical.

Merit Function	MAE [mm]	RMSE [mm]	MIN [mm]	MAX [mm]
SRC/CC	1.2732	1.5170	-2.0164	3.3672
MI	0.6929	1.2273	-1.4572	3.1376

Table 1: Tumor registration errors of cranio-caudal motion monitoring when using bone-suppressed Xray-images of different merit functions

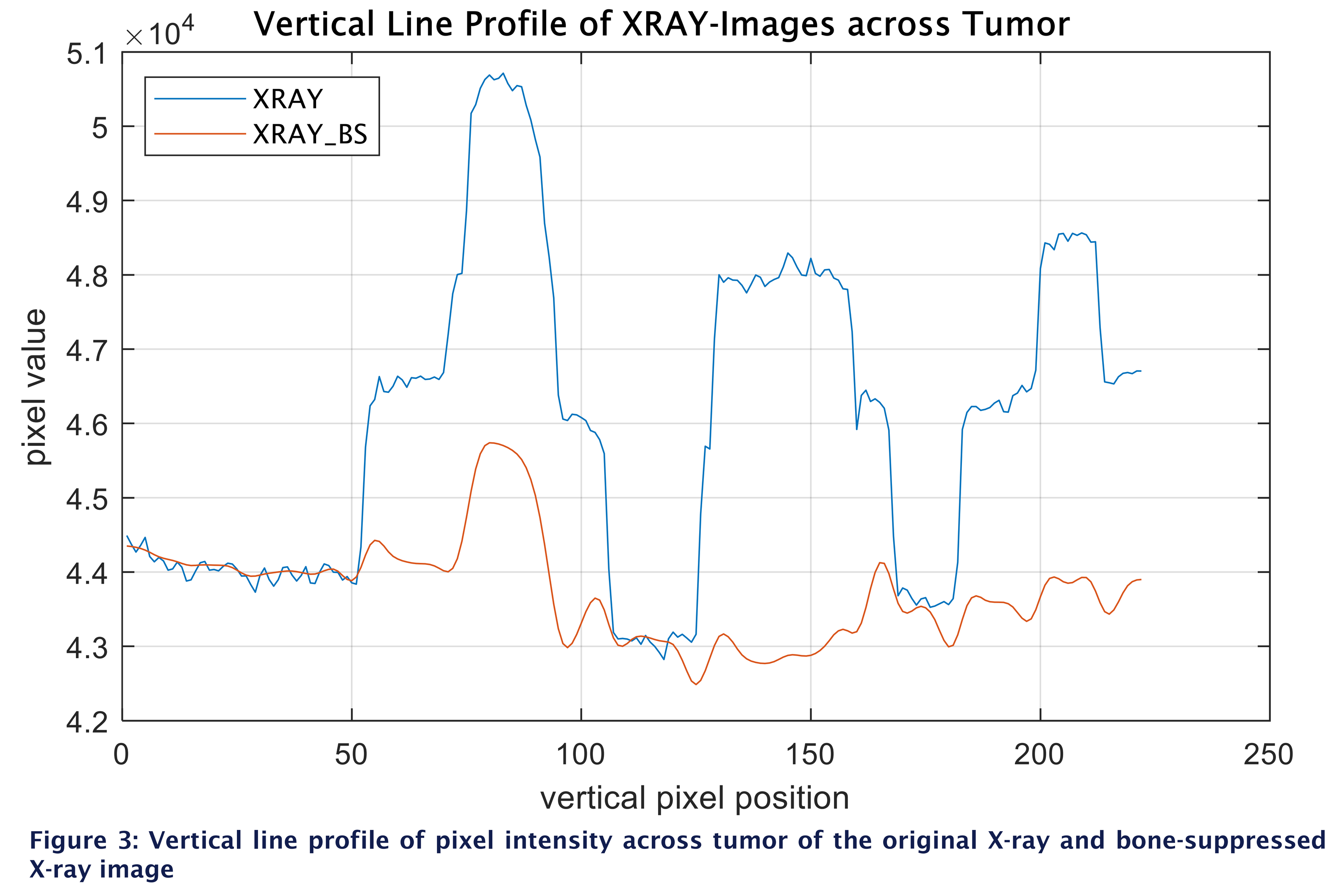

Figure 3: Vertical line profile of pixel intensity across tumor of the original X-ray and bone-suppressed X-ray image

Conclusion

The proposed bone suppression method allows tumor motion monitoring of tumors with high motion amplitudes (+/-3 cm) even in the case when ribs are present and tumor registration without bone suppression fails.

A further evaluation focusing on patient data will be a necessary step to make statements about the application and benefits in clinical practice.

References

[1] H. Furtado, C. Gendrin, J. Spoerk, M. Figl, D. Georg, and W. Birkfellner, "PO-0930: FLIRT: a software suite for real-time 2D/3D image registration for image guided radiotherapy," Radiother. Oncol., vol. 115, p. S485, Apr. 2015, doi: 10.1016/S0167-8140(15)40922-3.
[2] H. Furtado, E. Steiner, M. Stock, D. Georg, and W. Birkfellner, "Real-time 2D/3D registration using kV-MV image pairs for tumor motion tracking in image guided radiotherapy," Acta Oncol. (Madr)., vol. 52, no. 7, pp. 1464–1471, Oct. 2013, doi:10.3109/0284186X.2013.814152.
[3] N. Kostiukhina et al., "Advanced Radiation DOSimetry phantom (ARDOS): a versatile breathing phantom for 4D radiation therapy and medical imaging," Phys. Med. Biol., vol. 62, no. 20, pp. 8136–8153, Oct. 2017, doi: 10.1088/1361-6560/aa86ea.