An Alternating Image Registration Approach for Large Scale Bladder Deformations in Radiation Therapy

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Introduction

In adaptive radiotherapy, deformable image registration (DIR) is a crucial component for tasks such as contour propagation and dose summation. In the pelvic region, DIR of planning CTs to daily CBCTs is especially challenging. Organs such as the bladder deform in a way such that common DIR approaches struggle compensating for their strong variations, caused by e.g. varying bladder fillings. In this work, we introduce a novel alternating approach which aims to capture huge differences in bladder filling while maintaining accuracy in adjacent regions.

Materials & Methods

The introduced algorithm is alternating between a DIR step and a bladder segmentation refinement step and assumes a delineated bladder on the planning CT image. An initial DIR step is done preceding the main alternation procedure. It solves the optimization problem $\mathrm{NGF}\big(\mathrm{CT}, \mathrm{CBCT}(y_0)\big) + \mathrm{Curv}(y_0) \rightarrow \min$ using the so called normalized-gradient-fields (NGF) distance measure and a curvature regularizer (Curv) as described in [1]. The resulting transformation y_0 allows for an initial propagation of the CT bladder contour onto the daily CBCT. Hence, apart from the manually delineated bladder contour B_0 on the CT image, an initial bladder contour on the CBCT image is given as $B_1 := y_0(B_0)$. Incorporating these two structures, the proposed approach alternates between a step that refines B_k (with $k = 1$ in the first iteration) to an improved CBCT bladder contour approximation B_k^* and a mask penalty DIR step that drives B_0 on the planning CT towards the refined bladder contour B_k^* on the CBCT. This results in an updated CBCT bladder contour $B_{k+1} = y_k(B_k)$ being refined again in the next iteration, see Figure 1 for a visualization of the alternation scheme.

The mask penalty DIR approach adds the so called sum-of-squared-differences penalty $\mathrm{SSD}(B_k^*, B_0) = \int (B_k^* - B_0)^2 \, \mathrm{d}x$ to the optimization problem and is described in detail in [2]. This penalty enforces a closer match of B_0 and the current CBCT bladder approximation B_k^*.

The bladder contour refinement is based on a mesh representation, where a normal vector is assigned to each node. The contour is refined by moving each node to the maximum gradient magnitude value of the CBCT along the normal. The search range is 5 mm in positive and negative normal direction and is sampled with a step size of 0.5 mm. A hard constraint is applied in order to prevent “spikes”, based on a graph cut [3]. In order to limit deformation at the inferior bladder side, search ranges were restricted to ±2 mm in this area.

The scheme was stopped after five iterations as a higher number of iterations did not lead to an improvement of the contour. The new DIR scheme was evaluated on ten CT/CBCT male pelvis datasets. Using the propagated delineations on the CBCT images, Dice similarity coefficient values (DSC) were computed in comparison with manually delineated structures of femoral bones and bladder.

Results

Strong bladder DSC improvement was achieved for cases with poor overlap after the initial DIR (Case 4: 0.79→0.87, Case 5: 0.83→0.94, Case 7: 0.87→0.96). Slight improvement was achieved for two cases (Case 6: 0.85→0.89, Case 8: 0.84→0.88). Bladder DSC values for cases, which already achieved high DSC values after the initial registration, stayed at this high level (Case 0: 0.91→0.94, Case 1: 0.92→0.91, Case 2: 0.94→0.96, Case 3: 0.93→0.95, Case 9: 0.91→0.90). Average DSC values of the bladder increased from 0.88±0.05 to 0.92±0.03. Furthermore, the average DSC of femoral bones was kept constant at 0.94±0.02.

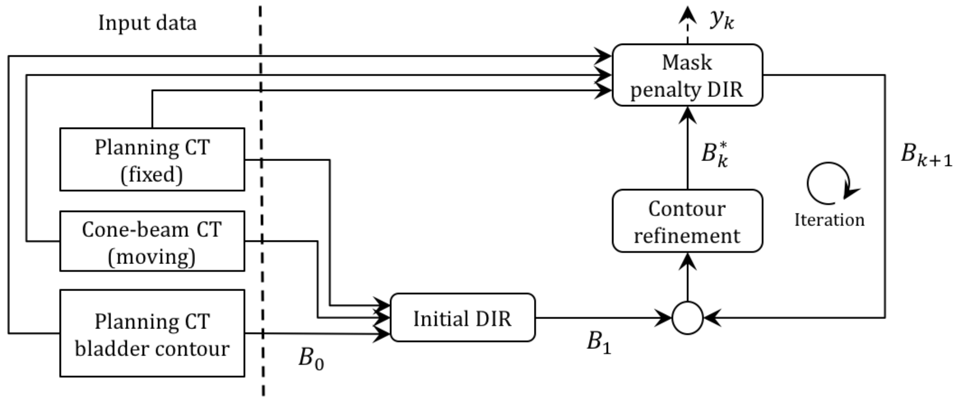

Figure 1: *Flowchart of the alternating procedure. After an initial DIR, the CT bladder contour B_0 is propagated to the CBCT image. This contour is refined as B_k^*, and then used for a mask penalty DIR. This results in a propagated contour B_{k+1} that is refined again in the next iteration.*

Discussion & Conclusions

The proposed registration scheme is targeting especially challenging cases with high differences in bladder volume. The obtained results show that bladder overlap in cases which performed poorly after the initial DIR could be strongly improved with the new approach. Additionally, those cases that already obtained good results after the initial DIR did maintain the high DSC values, yielding globally improved results. Furthermore, DSC values of femoral bones are still in a high range and were not influenced by the new scheme. With this, the presented approach clearly has potential to improve bladder overlap in cases where common DIR approaches cannot account for large deformations.

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References

[1] L. König and J. Rühaak, “A Fast and Accurate Parallel Algorithm for Non-Linear Image Registration using Normalized Gradient Fields,” in *IEEE ISBI*, 2014.

[2] J. Rühaak, S. Heldmann, T. Kipshagen and B. Fischer, “Highly Accurate Fast Lung CT Registration,” in *SPIE Medical Imaging*, 2013.

[3] X. Wu and D. Chen, “Optimal Net Surface Problems with Applications,” in *Automata, Languages and Programming*, 2002.

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