Deformable registration between CT and truncated CBCT for adaptive therapy dose calculation

Introduction Deformable image registration (DIR) is a crucial step in adaptive radiation therapy (ART) to deform the planning CT to the current CBCT for dose calculation and for contour propagation. CBCT images are sometimes truncated in the axial plane due to limited field of view (FOV). DIR between CT and truncated CBCT often leads to unphysical results, especially in and near missing regions, which may result in significant errors in dose calculation afterwards. The purpose of this work is to develop and evaluate a method to improve existing DIR algorithms to solve the truncation problem.

Methods We employed a newly developed DIR algorithm, named Deformation with Intensity Simultaneously Corrected (DISC), for the CT-CBCT registration. There are two key steps added to handle the truncation problem: 1) CBCT FOV extraction - the radius $r$ of the FOV in the transversal view of CBCT image can be estimated by calculating the number of non-zero voxels inside the cylinder with radius $r$; 2) moving vector field propagation - at each iteration of DISC, the calculated deformation fields that outside the FOV are replaced by a smooth extrapolation using those from the edge of FOV. The extrapolation equation we used is $dr(x) = \frac{dr(x')e^{-\alpha(l(x',x)/r^2)}}{r}$, where $dr(x')$ is the estimated moving vector at voxel $x'$ outside of FOVs, $x'$ is intersection point between line $x'x'$ and the circle centered at $x$ with radius $r$ in every transversal slice. $w$ is the width of the image, $l(x,x')$ is the distance between $x'$ and $x$, $\alpha$ controls the degree of deformation field propagation (DFP).

Experimental Results The performance of our method is evaluated on six head-and-neck cancer cases and two prostate cancer cases. The CBCT image is cropped artificially by using a preset FOV. CT image is registered to the cropped CBCT images using the DISC algorithm with and without DFP. Sample output is shown in Figure 1(a)~(c). DISC with DFP can yield correct registration result even in regions outside the FOV (yellow inset in Figure 1(c)). The DIR accuracy is quantitatively evaluated in the same FOV region of two images using normalized mutual information (NMI), normalized cross correlation (NCC) and feature similarity index (FSIM). The average NMI, NCC and FSIM increase from 0.638, 0.948 and 0.917, to 0.641, 0.951 and 0.919, respectively, when compared with DISC without DFP. Dose calculation is performed on the CT deformed to the complete CBCT as the ground truth, and on the CT deformed to the cropped CBCT. Inside the FOV, the relative L2 distance of dose distributions between the ground truth and that calculated on deformed CT with DFP is reduced from 9.25% to 1.41%, when compared with those without DFP (as shown in Figure 1(d)(e)).

![Figure 1. DIR results and dose difference. (a) cropped CBCT and CT before DIR; (b) cropped CBCT and deformed CT without DFP; (c) complete CBCT and deformed CT with DFP; (d) dose difference without DFP; (e) dose difference with DFP](image)

Conclusions We have developed a deformation field propagation method for DIR to register the planning CT and the CBCT image with small FOV. Tests on head-and-neck and prostate cancer cases have demonstrated that our algorithm can generate more accurate registration results for dose calculation.