A new geometrical method for 3D evaluation of non-rigid registration methods for radiotherapy in prostate cancer

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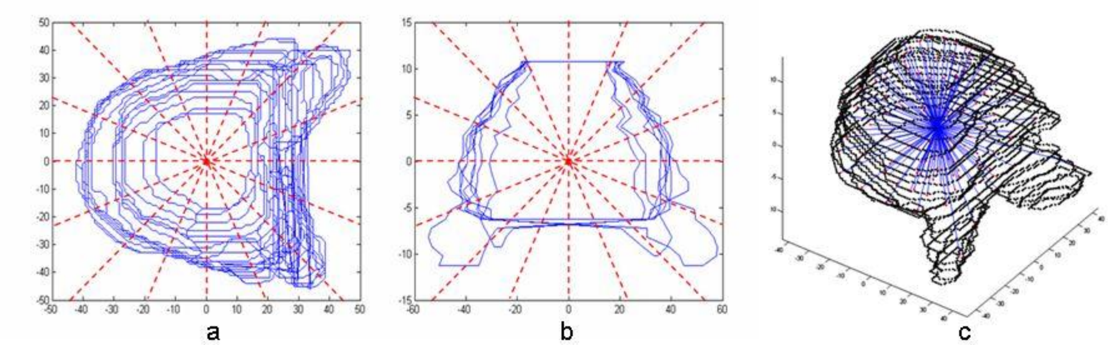
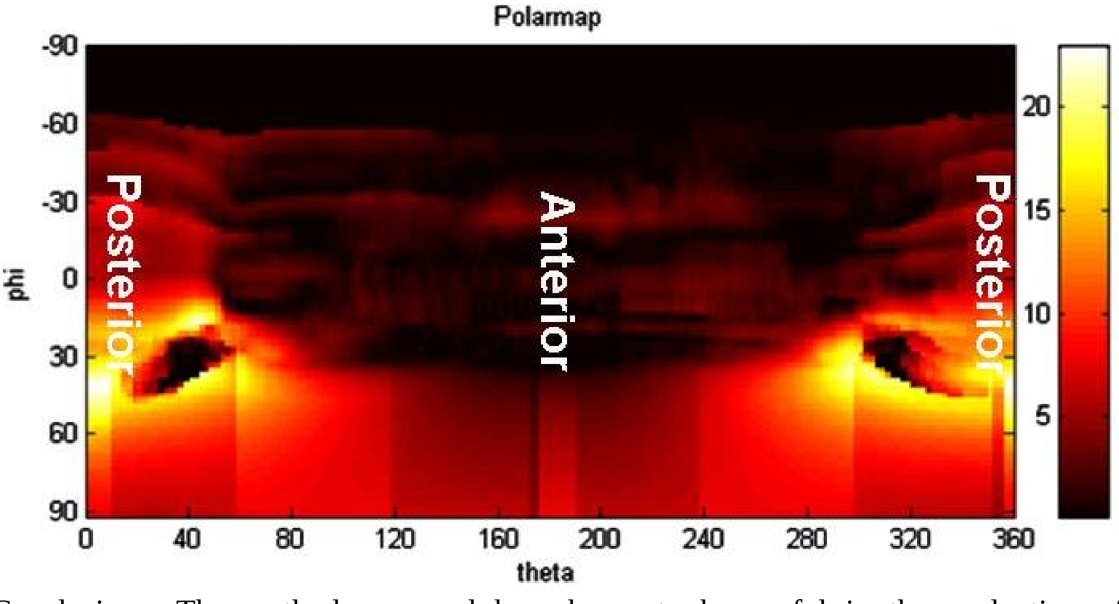
Purpose: Three-dimensional conformal radiotherapy aims at delivering a high dose of radiation to the tumour, while sparing the surrounding normal tissue to a maximum extent. Image registration is an essential tool for monitoring radiation therapies, since allows morphological comparisons in presence of anatomic variations. The evaluation of non-rigid registration methods is very complicated owe to the absence of a known pointwise correspondence. The use of analysis of variations in target volume delineations has been proposed in the past for the evaluation of non-rigid registration methods. Delineation of the target volume is usually accomplished by outlining the contour of the volume in each separate tomographic slice. In the studies of reference, the 3D surface is rendered from the contours by means of a Delauney triangulation. This geometrical method only works correctly for convex structures. However the volumes involved on pelvic anatomy, such as bladder or prostate including the seminal vesicles, have relevant concavities that introduce a huge error in the evaluation. A new geometrical method for the evaluation of convex-concave target volumes delineation is proposed.

Methodology: The geometrical method is based on sampling the distance between the centre of gravity of the target volume and the organ surface for a large number of directions (64800), using polar coordinates and combining two bidimensional analysis. The method consists of four steps. First, the centre of gravity of the organ is computed and set as the frame of reference. Second, all the contours draw on axial slices are represented on a single plane and they are intersected by a set of polar rays, homogeneously dividing the bidimensional frame of reference (see Figure 1a). The result is similar to intersecting the target volume with a set of planes perpendicular to the axial slices. Third, the intersection points for each polar ray are raised and linked to form a new set of contours. Finally, the second step is carried out, representing all the new contours on a single plane and intersecting them with a new set of polar rays, again in a bidimensional frame (1b). In this case, the new set of polar rays has to take into account the different dimensions of the voxel in the tomographic images; usually the pixel dimensions in each slice are equal, but the distance between slices is higher. Summarizing, for each control point the distance to the centre of gravity and the vector normal to the surface can be computed (1c).



In order to evaluate the performance of non-rigid registration methods, the delineations of the target volume in the reference image and in the registered template image will be compared. The translation of the target inside the body can be measured as the difference between the centres of gravity of the different target volume delineations. The statistical analysis of the deformation of the organ can be performed in several ways. If both centres of gravity in the reference image and in the registered template image are matched and set as frame of reference, the distance difference in every radial direction can be assigned as the deformation in this direction. If only the centre of gravity of the reference image is set as frame of reference, the distance measured perpendicular to the surface of the reference target volume must be used. In this case the distance measured along the radial direction should be multiplied by the angle between the vector normal to the surface and the radial direction.

Results: The results obtained in this study are 64800 control points per volume (one each solid angle of one degree) in images of radiotherapy planning for prostate cancer, in less than one second using a PC with a Pentium 4 3GHz CPU and 1GHz RAM and a Matlab implementation. Our Matlab implementation of Delauney triangulation method is unable to compute so much control points, and is obviously slower for the same number of scanning directions. The distance differences between the Delauney triangulation method and the method proposed tend to be zero in the convex regions of the volume. However, the differences between both methods in the non-convex regions are very important, with the maximum around the seminal vesicles in the prostate (22 mm), and close to the prostate in the case of bladder (17 mm). The polar map in Figure 2 measures the differences between both methods in the scanning directions, representing the distances by means of the colour gradation showed in the colourbar.ç



Conclusions: The method proposed has shown to be useful in the evaluation of variations on target volume delineation, giving a full three-dimensional description of the delineation variability. Its application to the evaluation of the performance of non-rigid registration methods requires the application of the method to a reference target volume and to a registered template target volume. The method works correctly in convex and no-convex structures, obtaining a better accuracy than the Delauney triangulation method, with a better computational performance.