

A Software Toolkit for Multi-Image Registration and Segmentation in IGRT and ART

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Introduction An essential step in radiation therapy is accurate three-dimensional segmentation of the target and organs at risk. Traditionally, this has been done by manual contouring on a slice-by-slice basis, but modern adaptive radiation therapy (ART) protocols can require segmentation of multiple daily images for each patient [1], increasing the pressure to develop automated methods for segmentation. Image guided radiation therapy (IGRT) also implies periodic 3D images taken at treatment time. Image registration may be used to align the target with its location in the planning image, and deformable registration can be used to place dose distributions from different days in a common “tissue-based” frame of reference so that the cumulative delivered dose can be assessed [2, 3]. Furthermore, deformable registration offers a potential solution to the problem of repeated daily segmentations, as image deformations can be applied to segmentations of the planning image to generate segmentations of the treatment image [4].

We have developed a new software tool for image analysis in radiation therapy bringing together research software for automatic and manual segmentation, and deformable and rigid registration, into a single usable package. The tool is designed with adaptive radiation therapy in mind. For manual segmentation, it extends functionality found in the treatment planning system PlanUNC [5]. In turn, the segmentation component of PlanUNC was a development of two earlier tools, IMEX [6] and MASK [7]. For automatic segmentation, the new tool permits two approaches. One approach relies on fitting a model called an m-rep to an image [8], and the other relies on deformable image registration [9]. A view of the main window is shown in Figure 1.

Manual segmentation. For manual segmentation, the tool contains a full suite of contour editing features. For instance, the user can draw contours, edit them by moving or cutting out points, copy and move them, and delete them. In addition, whole models can be duplicated and combined with other models by setwise operations such as union, intersection, and subtraction. Finally, models can

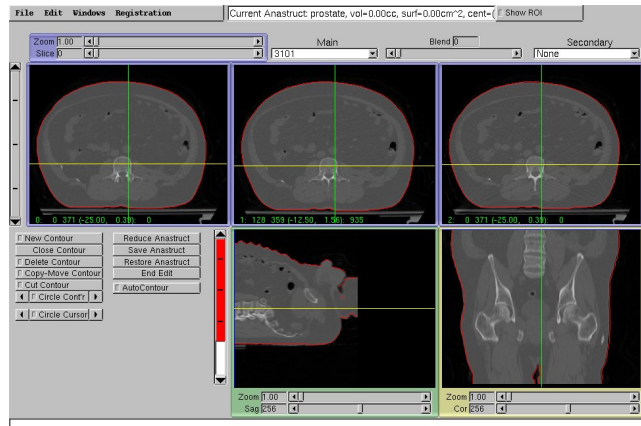


Figure 1: The primary display window.

be expanded and contracted, either in 3D or 2D (that is, slice by slice).

Models can also be generated by adjusting intensity thresholds, selecting a connected component to be flood-filled in a scale-sensitive manner, and then automatically contouring the filled regions.

The segmentation window is also used to compare multiple registered images, along with corresponding contours. This is important if consistency is desired between segmentations on different days. Two images can be viewed simultaneously via a blend slider, and a series of images can be shown in the form of a cine loop, along with the corresponding segmentations.

M-rep segmentation. M-rep segmentation [8] is a Bayesian approach in which a particular kind of generic 3D model of an organ is fit to an image using an optimization process. The optimization takes into account the plausibility of the shape the model is being asked to attain, and the degree to which the image intensities in the region around the model match those that would be expected near corresponding parts of the given organ.

The particular type of 3D model used is a *medial representation*, or m-rep. Discrete samples along a surface through the middle of the object are specified, and “spokes” point symmetrically outward from each sample point, the endpoints of the spokes marking the boundary (see Figure 2). The medial

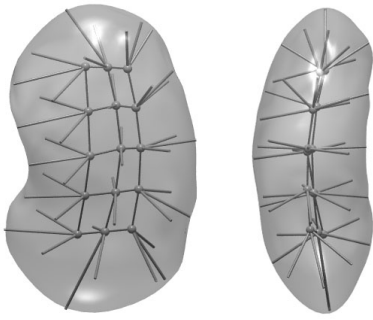


Figure 2: A medial representation of a kidney (two views).

representations provide an explicit connection between opposite sides of the model, making it easier to represent meaningful long-distance correlations than would a simple surface model. The model determines a coordinate system over interior and neighboring exterior points, and this coordinate system deforms along with the model, making it possible to analyze the statistical properties of image intensities relative to the model.

Deformable registration. The deformable registration algorithm [2, 9] deforms the image so as to minimize the mean squared intensity difference between corresponding voxels, subject to a penalty for the degree to which the deformation differs from the identity. To allow large deformations, a time parameter is included, and the deformation penalty is based on the velocity of change, rather than the absolute magnitude. The algorithm progresses by calculating image forces based on the gradient of the moving image and on the intensity differences, and simulates the flow of a highly viscous compressible fluid, carrying the image into better alignment. The resulting deformations can be used to deform segmentations generated on one image to another, and they can also be applied to dose distributions calculated using other tools.

Conclusion. The segmentation and registration tool provides a consistent user interface to apply and compare multiple segmentation methods to a single image, and across multiple images. It is being provided to the research community free of

charge.

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