Abstract
Optical flow methods (OFM) are widely used for deformable registration of images acquired at different times. OFM can also be used to establish correspondences between adjacent slices in a CT image data set. The pixel-to-pixel displacement matrices generated from the registration of adjacent CT slices offer precise mappings for contours, which in turn allows automated segmentation of anatomic structures. Generation of contours of lung, heart, esophagus, and spinal cord has been studied. Examples are given in this paper. OFM-based segmentation method has the potential to supplement the manual delineation approach that is currently used in radiation oncology clinics for radiation treatment planning.

Key Words
Optical flow, deformable registration, CT segmentation.

1. Introduction
The outlining of anatomic structures from computed tomography (CT) images as part of the process of radiation treatment planning has long been a difficult problem. In both 3D conformal and intensity modulated treatment planning the anatomic structures need to be visualized in order to assist the treatment planner in determining beam geometries and treatment portals that provide target coverage while minimizing the irradiation of normal anatomic structure. The delineated boundaries of anatomic structures are used to formulate the dose-volume histograms (DVH), an important measure by which radiation treatment plans are evaluated. The DVH displays the volumes of structures receiving specified doses, and from analysis of DVHs the radiation oncologist can assess the potential outcome of the radiation treatment.

The major problem with outlining anatomic structures on CT images is that this procedure is presently a manual, repetitive, tedious, and time-consuming procedure. The outlines are drawn on a slice-by-slice basis and may require a substantial amount of time per case. Because it is manual, developments in computer hardware will not significantly speed up the execution of this procedure. Efficient algorithms for automating this task are needed. Although present commercial radiation treatment planning systems offer auto-contouring options and contour interpolation between slices, these have significant limitations. The auto-contouring algorithms used are typically based on histogram segmentation. This approach works well for anatomic structures that have CT numbers that are significantly different from the CT numbers of their surroundings and are completely surrounded by CT numbers outside of the threshold values, such as lungs, bony structures, and the exterior contour of patient. Each of these structures may have regions, however, where histogram image segmentation algorithms do not work well. For example, this approach does not work well for structures bordered by tissue of the same density. The interpolation techniques assume a similarity between the contours drawn at the bounding end images and the images between them. The interpolation techniques make no use of image content information.

The purpose of the present paper is to demonstrate a proof-of-concept for a semi-automated method of delineation of regions of interest based on techniques of deformable image registration. An anatomic structure delineated on one axial CT image is similar in shape to the same anatomic structure on an adjacent slice. Consequently, a deformable image registration matrix can be generated to describe the registration of one axial CT image with the adjacent image. The elements of this matrix are two-dimensional displacement vectors of pixels from one image to the next. Once this deformation matrix has been determined, the matrix can be applied to map a contour of an anatomic structure delineated on one axial slice to an adjacent slice. This procedure can be repeated for the entire CT image data set to generate a complete set of contours for radiation treatment planning.

2. Materials and Methods
A gradient-based optical flow method (OFM) of deformable image registration was chosen [1,2]. OFM implicitly requires small displacements, less than one
pixel. This limitation is overcome in our implementation through use of a multi-resolution calculation method. Images are registered from coarse resolution to fine in multiple steps, allowing for large displacements between images.

CT images of the thorax for several patients were acquired under an institutional review board approved protocol to study tumor motion (MDACC ID00-202). Patient image data sets were obtained using a CT scanner (AcQsim, Philips Medical Systems, Cleveland OH) with 3 or 5 mm slice spacing. The images were sent to a CT simulation workstation (VoxelQ, Philips Medical Systems, Cleveland OH) where a radiation oncologist manually delineated the contours of the esophagus, heart, spinal cord, and each lung on every slice. The resulting images and contours were transferred to a commercial radiation therapy treatment planning system (Pinnacle3, Philips Medical Systems, Milpitas CA), with patient identification information deleted. The data was then transferred to a research workstation in either the native Pinnacle data format or the RTOG format [3].

The adjacent slices in each image volume are registered utilizing the 2D OFM software creating a displacement vector field for each adjacent slice. Manually obtained seed contours are extrapolated through an entire CT image volume using OFM for intra-thoracic anatomical structures. The displacement vector field provides an elastic image mapping between adjacent slices. The displacement vector field is applied to the contour points to move the contour from one slice image to the adjacent image.

Two methods of segmentation extrapolation are demonstrated. Contours are extrapolated through each adjacent image over the entire range of the structure. With multi-resolution, a drawn contour can be directly mapped to many slices that are not adjacent to the original contour. This has the advantage of minimizing the accumulated error and maintaining the contour on the boundary of anatomic interest. The quality of the mapping depends only on a single calculation and not on an accumulation of previous calculations and their compounding errors.

The esophagus, spinal cord, right and left lungs, heart, and airway at the carina structures have been evaluated. Each of the thoracic structures has been studied in this study. A single contour is propagated until in the judgment of the radiation oncologist it did not represent the structure of interest.

3. Results

The registration of two adjacent slides is shown in figure 1, where the original image is in 1a and the reference image in 1b. The difference between the original image and the reference is shown in 1c. Image 1d displays the calculated velocity matrix for the registration of original image to the reference. The estimated image from the registration is shown in 1e. Image 1f shows the difference between the estimated image and the reference image. Figure 1 shows an example of how precise the registration typically is.

The optical flow program was used to register contours for intra-thoracic anatomy structures, including lungs, esophagus, heart, spinal cord, and carina. Fig 2 shows an example of left lung contour registration on a prone CT scan set. The registered contour points follow the anatomy structure change very well. The displacement vectors, which indicate the anatomic structure changes in direction and dimension between the original image and the reference image, are also shown in Fig 2.

Fig 3 illustrates segmentation extrapolation of the esophagus contour across thirty-two images. The contours generated were all considered acceptable by the radiation oncologist and accurately represented the anatomic structure.

3. Discussion

As mentioned in previous sections, topological changes are problems in contour propagation using OFM. An example of this kind of failures occurs where bifurcation of the carina takes place. To avoid this, it is suggested that the physicians manually delineate the contours of anatomy structures of interest on a slice of every 20 to 30 slices. The program then propagates the contours on both directions to fill the remaining slices. If a topological change occurs between the manually delineated contours, the program still can propagate the contours from opposite directions and meet where the change takes place. In this way, physicians do not need to select the slices where topological changes occur. This is also an effective method to avoid error accumulation due to multiple steps of deformation matrix propagation that may magnify any error of the original contours delineated manually.

The optical flow software is originally designed to register 2D images of different time frames. This study extends the concept of time frames to adjacent slices of CT scans to allow elastic registration between slices.

4. Conclusion

Optical flow method is a powerful tool in CT image segmentation. The propagation of 2D anatomic contours to neighboring slices is achieved via a deformable image registration.
Fig 1. Example of image registration from a. original image to b. reference image. The difference between the original image and the reference is shown in c. Image d displays the calculated velocity matrix for the registration of original image to the reference. The estimated image from the registration is shown in e. Image f shows the difference between the estimated image and the reference image.

References


Fig 3. Esophagus contours propagate through 32 slices by deformable registration using optical flow method. The contour on Slice 1 is the only original contour delineated manually.