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Semi-automated CT segmentation using optic flow and Fourier interpolation techniques

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ABSTRACT

In radiotherapy treatment planning, tumor volumes and anatomical structures are manually contoured for dose calculation, which takes time for clinicians. This study examines the use of semi-automated segmentation of CT images. A few high curvature points are manually drawn on a CT slice. Then Fourier interpolation is used to complete the contour. Consequently, optical flow, a deformable image registration method, is used to map the original contour to other slices. This technique has been applied successfully to contour anatomical structures and tumors. The maximum difference between the mapped contours and manually drawn contours was 6 pixels, which is similar in magnitude to difference one would see in manually drawn contours by different clinicians. The technique fails when the region to contour is topologically different between two slices. A solution is recommended to manually delineate contours on a sparse subset of slices and then map in both directions to fill the remaining slices.

1. Introduction

The outlining of anatomic structures from computed tomography (CT) images, as part of the process of radiation treatment planning has become an issue with the advent of 3D conformal radiotherapy (RT) and intensity modulated radiotherapy (IMRT). Manual CT image segmentation of both tumor and normal anatomy has become an essential component of treatment planning. In both three-dimensional (3D) conformal treatment planning and IMRT treatment planning, 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 the normal anatomic structure. Normally, anatomic structures surrounded by tissue of similar density cannot be visualized on projection radiographs. However, these anatomic structures may be outlined on CT images, because the contrast afforded on CT images better delineates the features of the structures. Once segmented on the CT images anatomic structures are projected onto a digitally reconstructed radiograph (DRR). The delineated boundaries are also used to formulate dose-volume histograms (DVH), an important measure by which radiation treatment plans are evaluated.

2. Background

A major problem with outlining anatomic structures on CT images is that the procedure is done manually and is repet-

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itive, tedious, and time-consuming. Outlines are drawn on a slice-by-slice basis, and a skilled dosimetrist may spend an hour or longer on each case. Efficient algorithms are needed to automate this task. Although current commercial radiation treatment planning systems offer auto-contouring options and contour interpolation between slices, these tools have significant limitations. The auto-contouring algorithms used are typically based on histogram segmentation, which is also referred to as thresholding of CT voxel values. In one such algorithm, the treatment planner selects a pair of threshold CT voxel values that form boundaries for the CT values that comprise the region of interest. A point is found on the boundary of the region of interest where the threshold is crossed, and the boundary is traced all the way back to the initial point. 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. Examples of such structures are lungs, bones, and the exterior contour of the patient, although each of these structures may have regions for which this approach to image segmentation does not work well. This approach however does not work well for structures bordered by tissue of similar density with similar CT numbers. Contour interpolation techniques assume a similarity between the contours drawn at the bounding end images and the images between them and make no use of image content information. What is needed for the practical clinical cases is an accurate and robust automatic method of delineating soft tissue anatomy on CT images.

3. Design considerations

The purpose of the present paper is to demonstrate proof-of-concept for a semi-automated method of delineating regions of interest based on the techniques applied in deformable image registration. The new approach recognizes that the axial CT images used in radiation treatment planning are acquired at small intervals in the superior–inferior direction, typically 3–5 mm. The patient's anatomical features do not vary in large amounts over these distances. An anatomic structure delineated on one axial CT image has a similar relationship with surrounding organs 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 vectors with relatively small magnitudes relating the computed displacement or flow of pixels from one image to the next.

Once this deformation matrix has been determined, the matrix can be applied to a contour of an anatomic structure delineated on one axial slice to deform the contour 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.

For the original contour, the Fourier interpolation (FI) technique is used to make this task easier and faster. Only a few critical points are needed instead of tracing the whole boundary of the region of interest.

4. System description

4.1. Image data sets

Twelve different patient 3D CT data sets of entire body or pelvis, thoracic region with either 3- or 5-mm slice spacing are used for several segmentation experiments to generate lung, esophagus, heart, kidney, spinal cord, prostate, rectum, bladder, and gross tumor volumes (GTV).

4.2. Fourier interpolation

FI [1,2] is used in the first contour delineation. Instead of drawing the whole contour of a structure of interest on an axial CT slice, the user needs to pick only a few critical points that usually have high curvature along the boundary of the anatomical structure. The critical point sampling method gives a better contour fit than the equal-space sampling and other sampling methods. The equal-space sampling method selects points with equal intervals in space.

The Cartesian coordinates of the critical points, $X(n)$, $Y(n)$, are changed into complex coordinate $a(n)$,

$$a(n) = X(n) + jY(n), \quad n = 0, 1, 2, \ldots, N-1, \tag{1}$$

where n is the sequential number of a point.

The complex coordinates $a(n)$ are transferred to frequency domain by applying discrete Fourier transformation (DFT),

$$a(n) = \sum_{n=0}^{N-1} A(u) \exp\left\{\frac{j2\pi un}{N}\right\}. \tag{2}$$

where u means the uth spectrum in frequency domain and N is the total number of points, and

$$A(u) = \frac{1}{n}\sum_{n=0}^{N-1} a(n) \exp\left\{\frac{-j2\pi un}{N}\right\} \tag{3}$$

is called Fourier descriptor.

The zero-padding technique is used to increase the original N points to M points ($M>N$) on the frequency spectrum by adding nil energy points between the N points. In the frequency domain, the zero-padding $X_i^d[k]$ is expressed as

$$X_i^d[k] = \left\{\begin{array}{ll} LX^d[k], & 0 \le k \le \frac{N-1}{2} \\ LX^d[K-M+N], & M - \frac{N-1}{2} \le k \le M-1 \\ 0, & \text{otherwise} \end{array}\right\} \tag{4}$$

where $M = LN$, $L > 0$ is called interpolation factor. M is an integer multiple of N in the current version of the FI program.

Subsequently, the original points and the interpolated points in the frequency domain are transferred back to the Cartesian system using the inverse discrete Fourier transformation. The Cartesian resulting points then define the contour.