An Accurate 3D Segmentation Method of the Spinal Canal applied to CT Data

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Abstract. With the modern treatment planning techniques the accurate definition of the target volume as well as the organs at risk is a crucial step for the treatment outcome. One of the key organs that must be protected during the irradiation treatment is the spinal cord. Nowadays, high resolution computed tomography (CT) data are required to perform accurate treatment planning, and there is the demand for quick but accurate segmentation tools. In this work we present a very simple approach that can accurately extract the spinal canal in three dimensions (3D) from CT images. The user must define only the starting point for the algorithm and the rest of the process is performed automatically. The core of our method is a boundary-tracing algorithm combined with linear interpolation techniques in the longitudinal (z) direction.

1 Introduction

Segmentation is the process that separates an image into its important features (primitives) so that each of them can be addressed separately. Humans can perform this task using complex analysis of shape, intensity, position, texture, and proximity to surrounding structures. To perform a similar procedure automatically using a computer since today has been proved a very difficult task. In other cases where simpler anatomical regions with a very distinguishable shape must be identified an algorithm can perform this task. Image segmentation is currently used into several medical imaging applications that involve diagnosis or treatment.

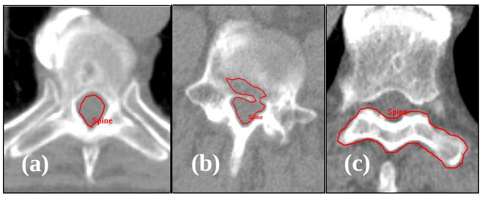
Among several treatment applications radiation therapy treatment of the cancer is an era where segmentation of anatomical volumes is an essential procedure. The physicians and physicists have to deal daily with large amount of data that must be segmented accurately and within a reasonable time frame. Standard radiotherapy techniques as well as the modern 3D treatment planning techniques like intensity-modulated radiotherapy aim to maximize the dose delivered to the target while minimizing the exposure of the dose-sensitive structures to high dose, thus increasing tumor control probability without increasing normal tissue complications [1, 2, 3]. Every calculation of the irradiation field position, orientation and size is done based on the shape and location of the target volume and the surrounding organs at risk. In addition to the geometric parameters that are calculated based on the volumes of interest (VOIs), the calculation of the dose distribution is directly related with the characteristics of the VOIs. One of the key organs that must be protected during the irradiation treatment in cases of neck and paraspinal tumors is the spinal cord. Traditionally the segmentation process is done manually on a slice-by-slice base. Nowadays usually high-resolution CT data are used (60 to 120 slices). Therefore the overall manual segmentation process could last several minutes. In this work we present an algorithm that can be used for the accurate semi-automatic segmentation of the spinal cord in three dimensions from CT images. Our method is basically composed from an edge detection algorithm, which is applied on the original, axial CT images.

2 Methods

In this work the implemented method is based in 2D boundary tracking (BT) algorithm [4,5], and it works at one image level at the time. In the case of the CT modality the algorithm is applied on the original (axial) cross section images. The BT algorithm requires an initial point to start the tracing of the edge of the object under investigation. The initial point travels to the vertical or horizontal direction until and edge of the investigated object is reached. Then the algorithm will start to exam the surrounding pixel of that edge and check whether they belong to the current edge or not. The algorithm uses a constant threshold selection with levels 50 to 100 HU.

The BT algorithm traces the edges with detail providing high accuracy to the description of the contour shape. However, the final contour shape contains sharp edges giving an uncomfortable optical effect. Therefore, we decimate the original number of contour points about 40%, smoothing simultaneously the contour shape. The main drawback of the BT, is that is a binary approach and hence is very sensitive to gray value variations. If the threshold value is not selected properly then the system will fail to detect the appropriate canal shape. This can be very often the case when the vertebra’s shape is interrupted from tumor metastasis or bone osteoporosis. Most of the inaccuracies of the segmentation method require the user intervention to optimize the result. An example of contour tracing using edge detection on single slice can be found in Fig. 1. To overcome this limitation we calculate a secondary opacity volume from the original CT data based on the well-known approach from Levoy et al [6], that is very often used to visualize surfaces from scalar volume data in volume rendering. This approach allows the comprehensive representation of tissue boundaries compared to the conventional thresholding techniques (see Fig. 2).

An error that usually occurs is when the user attempts to define the starting point for the algorithm. Due to the restrictions of the BT mentioned above, in this case it is not possible to initialize the tracing process from an arbitrary slice. Instead, a slice with closed vertebra’s canal must be selected from the user. Due to this limitation the user must be trained under the trial-and-error principle until the wanted contour is found. As solution to this problem we developed an angular ray-casting algorithm that enables the tracing of the vertebra location in an angular behavior using predefined values of angles. This approach is activated only if the BT fails to trace the spinal cord (see Fig.1c.). In order to generate the final contour shape we interpolate the traced points using the spline approximation (see Fig. 3).



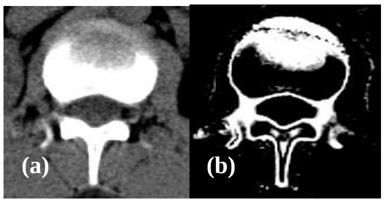
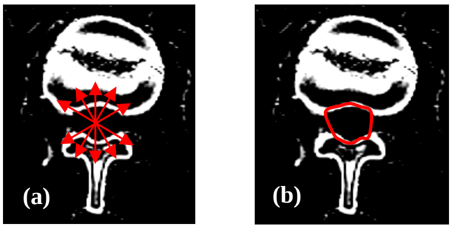


Fig. 1. Single slice edge-detection of the spinal cord. *In (a)* Accurate detection of spinal cord. *In (b)* Inaccurate detection of spinal cord. *In (c)* Unable to detect the spinal cord.

Fig. 2. Difference between simple image thresholding and gradient detection. *In (a)* Discontinuity on the vertebra visualized using original HU. *In (b)* The same structure after applying the gradient edge detection algorithm.



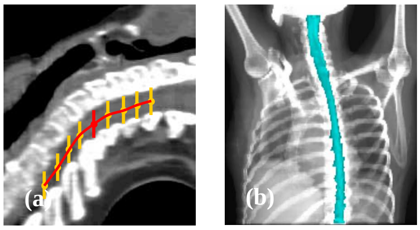


Fig. 3. Contour generation with the 2D ray-casting approach. *In (a)* The 2D ray-casting approach applied on an angular base. *In (b)* The generated contour after applying the spline interpolation to the traced points.

Fig. 4. *In (a)* Sagittal view of the neck region. Propagating the tracing point along the spinal canal. *In (b)* 3D reconstruction of the spinal cord.

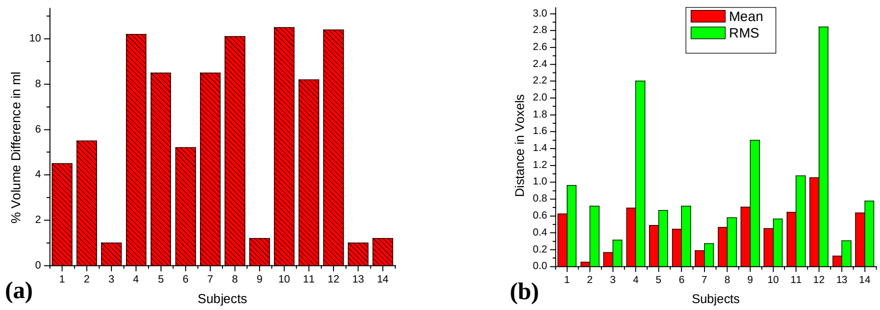


Fig. 5. Comparison of manual and computer traces contours. *In (a)* The percentage of volume difference in ml. *In (b)* Mean and RMS values between contour boundary distances.

In order to expand the approach in 3D we have to propagate the contour tracing point in both direction cranial and caudal from the user selected initiation point. As a new starting point we select the center of the detected contour, shifted at ±1value in the Z direction. In the new slice level the BT is applied using the new starting point. If the traced contour has different characteristics (e.g. area, relative location, average value of HU) in relation to the previous traced contour then it is rejected. This process is repeated for every slice. The rejected contours are replaced with linear interpolated contours from the key contours (generated ones) (see Fig. 4.).

3 Results

The algorithm was evaluated using 14 CT datasets from 14 arbitrary selected subjects. All subjects were scanned using spiral CT (Siemens Somatom Plus 4) with equal slice thickness and space. Overall 1229 slices with 3mm thickness were collected. The segmentation accuracy was assessed by comparing the automatic computer-based segmentation with results obtained by manual analysis. Differences on the contour border on each slice level were assessed by computing the mean and rms distance between the computer defined borders and the manually defined borders [7]. In addition, the overall difference of the spinal cord volumes was assessed between the computers defined and the manually defined structures. These results are shown in Fig. 5. The range of variation in volume measurement was 1.0%-10.2%, with a mean variation of 6.14% ± 3.82% (mean ± standard deviation). The range of variation in boundary distance measurement was 0.05-1.05 in voxels, with a mean variation of 0.48±0.27. In addition the algorithm provides good speed performance since 1-2 seconds are needed in average in order to segment a volume with 90 slices on a Pentium III 933MHz processor.

4 Conclusion

In this work a new method for semi-automatic 3D segmentation of the spinal cord is proposed. The method is based on the boundary tracking method applied on each slice level. To create the 3D tracing effect the initiation point is propagated cranial and caudal from the user defined point. The algorithm provides an acceptable accuracy and excellent speed performance for daily clinical use.

5 References

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