A Semi-Automated Technique for Vertebrae Detection and Segmentation from CT Images of Spine

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***Abstract*—Spine or backbone forms a supportive structure for all vertebrates, which is composed of complex bones known as vertebrae. Spine related pathologies are common and they are analyzed with help of various medical imaging techniques. Thus the detection and segmentation of vertebrae is gaining prime importance, as it can be used for the clinical analysis of spine. There are many semi-automated and automated approaches which are used to detect and segment individual vertebra from computed tomography (CT) images. But most of these approaches do not provide satisfactory results due to the anatomical similarities between the adjacent vertebrae and the effect of underlying artifacts. So to overcome these problems, a framework for individual vertebrae segmentation from CT images of spine is put forward. First of all, the vertebral body is identified with the help of iterative Normalized-cut algorithm which uses eigenvalue decomposition for the detection procedure and the segmentation of individual vertebra is done using region based active contour method .**

***Index Terms*—Anisotrophic diffusion, adaptive histogram equalization, morphological opening, Normalized-cut, region based active contour, Thresholding.**

I. Introduction

Spine or backbone plays a significant role in the day-to-day activities of all vertebrates. It provides the supportive framework and forms a bony chamber to protect the spinal cord. Spine-related pathological change is commonly assessed with X-ray, magnetic resonance (MR) and computed tomography (CT) imaging techniques. For clinical analysis, detection and segmentation of vertebrae is of prime importance as it can be used to identify various abnormalities affecting spine such as scoliosis, spinal fractures, disc degeneration, disc dislocation etc.. Among the various medical image processing techniques, image segmentation is a crucial step to analyze the given image. The type of medical image and the characteristics of the problem being considered plays an important role in the selection of various segmentation techniques and level of segmentation. The medical images obtained by various imaging techniques such as X-ray, computed tomography (CT) and magnetic resonance imaging (MRI) seems to be highly ambiguous and complex because of the restrictions imposed by image acquisition, pathology and biological variations [1]. The existing medical image segmentation methods can be classified into region growing methods, clustering approaches, energy minimization approaches, statistical shape model approaches and so on. Among the various methods, region growing algorithm fails to segment vertebrae because change in intensity caused due to noise artifacts significantly affect segmentation [5]. Clustering based approaches provide unclear boundary if the seed point is not properly identified [2]. The statistical shape model approaches to segment vertebrae estimate the expectations about the shape of an object of interest from series of known images from the training set [12, 13]. But most of the approaches based on statistical shape model are sensitive to variations in pose parameters. Graph based approaches such as graph-cut suffers from leakage problem if the energy minimization is not proper [8]. So to avoid such ambiguities and complexities, a semi-automatic technique has been put forward to segment individual vertebra in CT images, in which intended region of spine along is manually selected while the underlying process for detection as well as segmentation is automatic. In the proposed method, iterative Normalized-Cut algorithm is used for detection and individual vertebra segmentation is done by minimizing an intensity based energy function using region based active contour method.

II. Methodology

The entire process consists of two subsections: First section deals with vertebrae detection from CT image of spine. The detection stage consists of three processes: pre-processing, vertebrae detection and detection refinement. The iterative normalized-cut algorithm is used for vertebrae detection and it uses eigenvalue decomposition procedure for identifying the vertebral body. Second section deals with individual vertebra segmentation. For this, mask corresponding to each vertebra is created and with reference to this mask an initial contour is

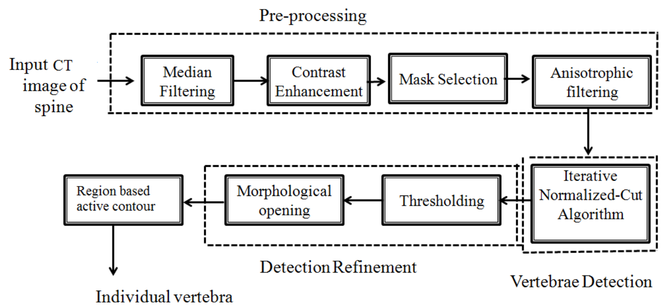

Fig. 1. Proposed block diagram for detection and segmentation of individual vertebra from CT image

set. This contour is evolved to object boundary by minimizing an energy function.

A. Spine detection

There are many algorithms that exists for vertebrae detection in CT images like support vector machines(SVM)[16], adaptive boosting algorithms(AdaBoost)[10] and so on, but all these techniques requires intense training phase. The training stage is expensive owing to complex computations that are used to reflect changes in vertebrae caused due to any pathologies or abnormalities. If this intense training is avoided, the detection may produce false results. So the detection using iterative normalized-cut algorithm is comprehensive in the sense that it eliminates the need for training stage and the vertebrae region with any type of abnormalities can be detected correctly. The importance of vertebrae detection is that, it serves as a pre-requisite for the spinal curvature estimation.

1) Preprocessing: Noise removal is an important step in medical image processing. For the detection process to be accurate, the input image should be free from all type of artifacts. Images of body parts acquired using different imaging modalities like magnetic resonance imaging, computed tomography, ultrasound and X-ray imaging are corrupted by noises artifacts such as speckle noise, Gaussian noise, salt and pepper noise etc.. In the proposed framework, the pre-processing stage for noise removal includes median filtering, contrast enhancement, mask selection and anisotrophic filtering.

- Median Filtering

X-ray and CT images may be corrupted by salt and pepper noise during acquisition and these are mainly removed by linear filters. But the application of linear filters may blur the edges. So to avoid such edge distortions non linear filter are used. In this work, median filter is applied for salt and pepper elimination, where pixels are ranked based on intensity and the value of the pixel under evaluation is replaced by the median value of the surrounding pixel values.

- Contrast Enhancement

Due to change in acquisition parameters, CT images may suffer low contrast and hence, edges and object of interest may not be visible properly. So, its grayscale value is enhanced by using CLAHE (Contrast Limited Adaptive Histogram Equalization). It acts on small regions of image called tiles and each tiles contrast is improved by calculating several histograms.

- Mask Selection

Mask selection is done manually. The advantage of this method is that user can freely select the region of interest.

- Anisotrophic Filtering

It is mainly done to remove the speckle noises affecting X-ray and CT images, which is nothing but random multiplicative noises. Anisotrophic filtering consists of two steps [11]. Firstly the image characteristics are described with the help of a second moment matrix called structure tensor J_p which is given by:

$$J_p(\nabla u_\sigma) = G_p * (\nabla u_\sigma)^T) \tag{1}$$

where $G_\sigma$is the Gaussian kernel with standard deviation ρ and u_σ represents the Gaussian smoothen image. Local orientations of the image is given by eigen vectors of J_p and the local contrast along these directions are given by the eigen values of J_p. Then this structure tensor is converted into another matrix called diffusion tensor for performing diffusion filtering using the equation

$$\frac{\partial u}{\partial t} = \nabla.(D\nabla u) \tag{2}$$

where the evolving image is represented by $u(x, t)$, diffusion time is denoted as t and D equals diffusion tensor. Diffusion filtering is done by applying a non-linear diffusion process along the structure tensor directions which will reduce the noise while preserving the edges and will also smoothen the edges by removing the gaps due to noise. This diffusion filtering is iteratively repeated and the number of iteration is set by the user which control the amount of smoothening. Rotation invariant anisotropic diffusion is used for structures having curvature such as the vertebrae.

2) Vertebrae detection: After the pre-processing stage, the vertebral region is identified using normalized algorithm [10, 15]. There are two steps in normalized-cut framework : similarity measurements and normalized cut process. The first step computes the similarity between the pixel and this value is set as the weight on the edge. To simplify the computation , a specific threshold criterion is used to set the edges between two nodes and the cut value is the total weight on these edges. Weighting function used is the euclidean norm of the difference between weighting feature (Intensity value).
Now, in the detection stage, the vertebral region has to be correctly identified by separating image in two parts, i.e. vertebrae and background region. For this, two matrices need to be defined W and D which are of same size. The matrix W is the similarity matrix with element $w_{i,j}$ as the similarity between the i^{th} pixel and the j^{th} pixel and diagonal elements of W are taken to form the diagonal matrix D, each diagonal element d_i contains the sum of all the elements in i_{th} row of W. With these two matrices, the minimum normalized cut

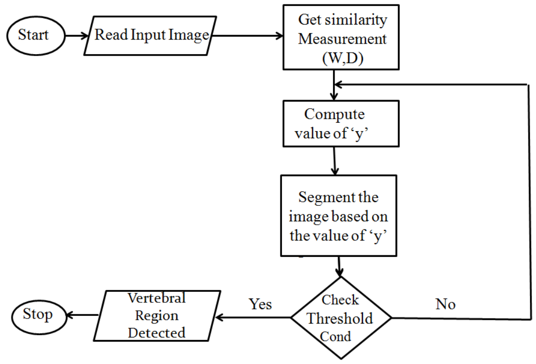

Fig. 2. Flow chart for normalized-cut detection

value to divide image V into two parts A and B is found out by solving equation given by:

$$minN_{cut} = min_y \frac{y^T(D-W)y}{y^T Dy} \tag{3}$$

where W is the similarity matrix and D is the diagonal matrix. Each element in the column vector y indicates the attribute of each pixel to the normalized cut process i.e. eigenvalue matrix corresponding to the vertebral region. Equation (3) can be again simplified into a general eigen value dimension as follows:

$$(D-W)y = \lambda Dy \tag{4}$$

From the column matrix y, the second smallest eigen value is selected for vertebrae detection as it contains the information regarding the vertebral body. Since the values in y contains all real numbers, a threshold value should be defined to separate pixels into distinctive groups. Flow chart shown in figure 2 summaries the whole detection process.

3) Detection Refinement: After the detection of vertebral region using normalized cut algorithm , for refinement purpose, thresholding followed by morphological opening is done. Thresholding binarizes the grayscale vertebral body while morphological opening removes all the unwanted background values detected as object in the output image [7].

B. Individual vertebra segmentation

For the segmentation of individual vertebra, a prior mask corresponding to each vertebra has to be created, which is a binary image obtained from the refined detection result using connectivity technique. Based on this prior mask, initial curvature is set and it is evolved to the object boundary by minimizing an intensity based energy function [1, 3, 7, 9, 14]. Since the ultimate aim is to segment individual vertebra, this mask for each vertebra is iteratively created and evolution of curve will continue upto maximum number of iteration set.

Algorithm for individual vertebra segmentation is as follows
1.Construct a binary mask corresponding to individual vertebra based on largest connective component.
2.Set the number of iterations, say 'n'
3.Set the initial contour based on prior mask
4. Distance transform of the mask is calculated to get the Euclidean distance.
5.Find the interior and exterior points from distance transform array.
6.Based on the interior and exterior points, interior and exterior mean of the corresponding region in the input image is calculated.
7.Calculate the energy function for curve evolution which is the square of difference between exterior and interior means i.e. Mean Separation energy
8.During each iteration, the curve is evolved to the object boundary.
9.Repeat steps 4 to 7 until maximum number of iteration is reached.

III. Results and Analysis

The input for the detection stage is the CT image of spine obtained from the website (as open source)
$www.med.uottawa.ca/radiology/Neuroradiology/eng/CT Unit.html$
$https://www.cedars-sinai.edu/Patients/Programs-and-Services/Imaging-Center/For-Patients/Exams-by-Procedure/CT-Scans/CT-Scan-of-the-Lumbar-Spine.aspx$
The view of the image is sagittal. The simulation platform used is MATLAB R2010a.

A. Spine Detection

1) Input image: The input CT image of spine in sagittal view is shown in figure 3.

Fig. 3. CT image of spine (sagittal view)

2) Median Filtering: CT images may be contaminated by salt and pepper noise. This noise is removed by median filtering and is as shown in figure 4. Median filtering performs the denoising of image based on median kernel. Kernel size used is 3x3.

3) Contrast Enhancement: It is necessary to improve the contrast of CT images. For this purpose, contrast limited adaptive histogram equalization(CLAHE) is used and is shown in figure 5. The distribution parameter used is uniform and so the output histogram of each tile will be uniform.

Fig. 4. Denoised image

Fig. 5. Contrast enhanced image

4) Mask Selection: Vertebrae region alone is selected with the help of matlab function $ginput$. The $ginput$ function identifies two points from the current axes and returns their x- and y-coordinates in the x and y column vectors. These coordinate values are used to set a rectangular boundary for the mask which is shown in figure 6(a). For the selected portion, anisotrophic filtering followed by iterative normalized cut algorithm has to be applied. In figure 6(b) mask region is highlighted using ones and the remaining portion is set to zeros.

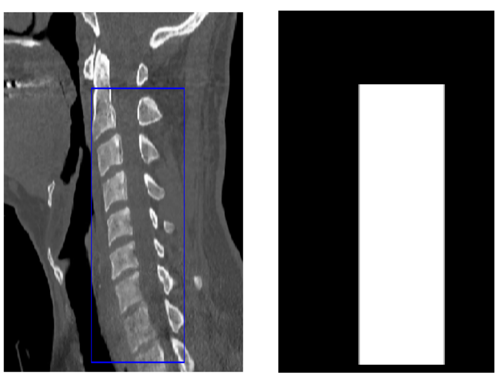

Fig. 6. (a) Mask selection (b) Mask initialization

5) Anisotrophic Filtering: The figure 7 shows anisotrophic filtering applied to mask region. During the median filtering , the edges are distorted due to the zero padding. So, aniostrophic filtering will smooth out the image edges removing gaps due to noise. Also, this smoothening will remove the noise artifacts in the image including speckle noise. The number of iterations is set by the user, and will determine the amount of smoothing. The diffusion time given here is 5 seconds and the scheme of diffusion used is rotation invariant.

Fig. 7. Speckle Noise Removal

6) Iterative Normalized Cut: For the detection of vertebral region from the CT image, iterative normalized cut algorithm is applied. The normalized cut value for bi-partitioning the image into vertebrae and background is found out by eigen value decomposition and the result shown in figure 8.

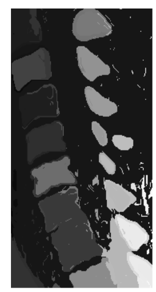

Fig. 8. Vertebrae Detection using Normalized-cut algorithm

7) Detection refinement: The normalized cut gives a gray scale image of the vertebral region, so thresholding is done to binarize the image and figure 9(a) shows the thresholded image. The threshold value is selected based on the mode value; i.e. the mostly occurring value. The thresholded image contains some unwanted regions other than the vertebrae. So to remove the small unwanted regions, morphological opening is preformed. Figure 9(b) shows the final refined image. The morphological opening removes all connected components (objects) whose area is less than 30 pixels and the default connectivity used is 8.

B. Individual Vertebra Segmentation

After the detection refinement, the binarized image corresponding to the vertebral region is obtained. From the resultant binary image, a mask corresponding to each vertebra is obtained using connectivity property. Based on this prior mask, an initial contour is set and the intensity based energy function obtained based on statistical mean is minimized to evolve the curvature to individual vertebrae. The curve evolves upto maximum number of iterations set. Figure 10 shows result of individual vertebra segmented using region based active

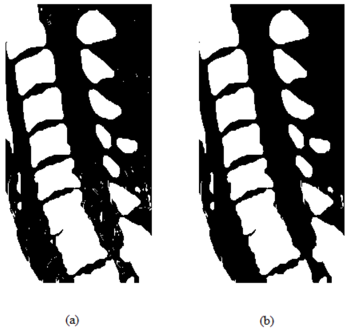

Fig. 9. (a)Thresholding applied to N-cut result (b)Morphological opening

contour technique and figure 11 shows how this technique works when applied to a fractured spine. Here, the maximum number of iterations set is 70. The ratio of total number of segmented vertebra to the total number of vertebra in the given spine gives the segmentation accuracy.

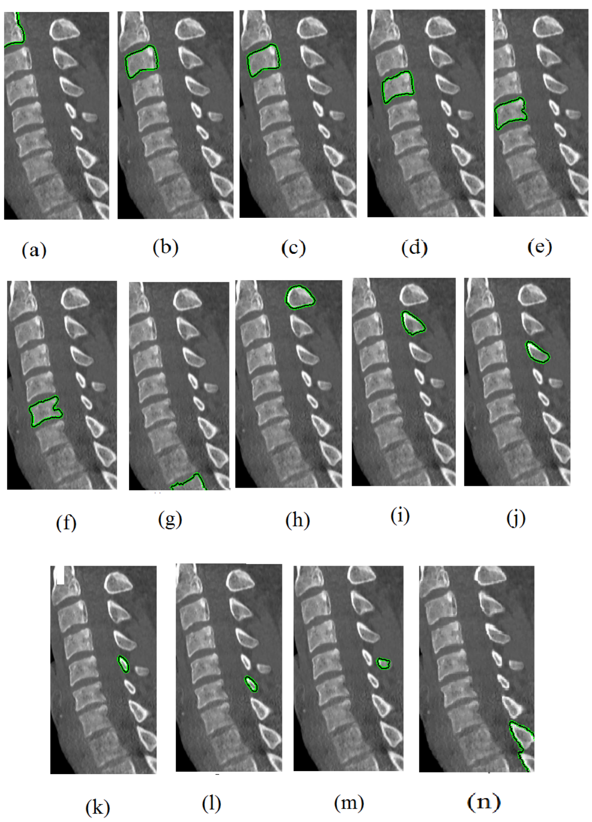

Fig. 10. (a)-(n) shows the segmentation results of individual vertebra along with its spinous structures.

While comparing with existing methods [2, 10, 12, 13], this method has the advantage of being a training-free segmentation technique, as it eliminates the need of intense training phase to reflect the complex shape of vertebrae. This proposed procedure is less complex and faster compared to other segmentation algorithm like SVM and Adaboost, and it provides good segmentation results.

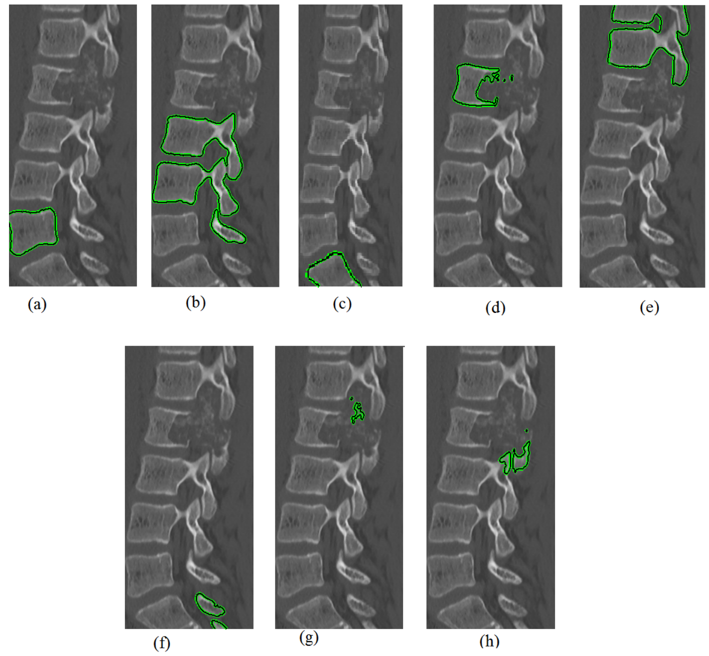

Fig. 11. (a)-(h) shows each vertebra along with spinous structure are segmented in a CT image of fractured spine.

IV. CONCLUSION AND FUTURE SCOPE

The ultimate intention of this work was to segment individual vertebrae from CT image, which may be a beneficial aid for medical diagnosis of spinal ailments. The iterative normalized-cut algorithm has been used for vertebrae detection and has provided satisfactory results in CT images. Yet its accuracy has to be improved for non-clear CT images that contain weak, unclear boundaries and also detection has to be made robust in case of any missing information in occluded images . Using region based active contour individual vertebra was segmented. In this method initial contour is set based on prior mask and is automatically evolved to object boundary by minimizing intensity based energy function. This detection followed by segmentation can be an important tool for analysis of scoliosis. The method for individual vertebra segmentation is not an optimal method, but seems to be simple and faster method to identify vertebrae and its associated regions such as spinous structures. From the analysis result , it is seen that segmentation results produce false results in the case of closely spaced vertebrae. The strength of this approach is that, it provides satisfactory results for almost all views of spine in CT images rather than a specific image, by varying the parameters in detection and segmentation stage. The analysis was done in two cases: (i) Normal spine CT image (ii) Fractured spine Ct image. In both cases, a region mask consisting on 17 and 10 vertebra was selected, out of which two or three vertebrae were not detected accurately i.e. false detection. These false detection occurred when the spacing between the adjacent vertebra was very narrow and also due to intensity similarity. In future, the accuracy has to be improved and an algorithm has to be developed to estimate the spinal curvature so as to identify various abnormalities affecting the spine such as scoliosis, disc degeneration and disc dislocation.

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