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Automatic segmentation of vertebral contours from CT images using fuzzy corners

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ABSTRACT

Automatic segmentation of bone in computed tomography (CT) images is critical for the implementation of computer-assisted diagnosis which has increasing potential in the evaluation of various spine disorders. Of the many techniques available for delineating the region of interest (ROI), active contour methods (ACM) are well-established techniques that are used to segment medical images. The initialization for these methods is either through manual intervention or by applying a global threshold, thus making them semi-automatic in nature. The paper presents a methodology for automatic contour initialization in ACM and demonstrates the applicability of the method for medical image segmentation from spinal CT images. Initially, a set of feature markers from the image is extracted to construct an initial contour for the ACM. A fuzzified corner metric, based on image intensity, is proposed to identify the feature markers to be enclosed by the contour. A concave hull based on α shape, is constructed using these fuzzy corners to give the initial contour. The proposed method was evaluated against conventional feature detectors and other initialization methods. The results show the method's robust performance in the presence of simulated Gaussian noise levels. The method enables the ACM to efficiently converge to the ground truth segmentation. The reference standard for comparison was the annotated images from a radiologist, and the Dice coefficient and Hausdorff distance measures were used to evaluate the segmentation.

1. Introduction

Devising an automatic method for detection and segmentation in medical images poses varied challenges [1]. Formulating an effective delineation technique for extracting the region of interest (ROI), in complex structures like the spine, is an arduous process. In order to assist in this process, various semi-automatic techniques are prevalent for segmenting the object of interest, including methods based on a global threshold [2]; however, a global threshold selection is not straightforward. Use of a single hard threshold is considered a source of segmentation errors [3]. Additionally, the pixels assigned to a single class need not necessarily form a coherent region since spatial locations are ignored. Histograms are drawn, and the valleys are identified as potential candidates for the global threshold. Multiple thresholds would be necessary if there were more peaks.

Active contour methods (ACM) are employed widely on medical images for segmentation [4–6]. In these methods, an initial contour, which evolves based on image gradients, is specified for extracting the desired objects [7]. The placement of contour sometimes becomes extremely important, because the contour might start deviating from its intended track if the image forces are not very strong. Convergence is faster if the contour is placed closer to the ROI so that it does not get attracted to the false edges that are likely to emerge from spurious noise and artifacts. The sensitivity of convergence to contour initialization was analyzed in [8] and the authors proposed an alternate means to achieve accurate segmentation based on neighborhood information. The size and number of medical images has increased at an alarming rate, necessitating the development of robust automatic segmentation methods. ACMs are a viable option for the automatic segmentation of medical images if robust computational methods for contour initialization are made available.

A brief literature review of the reported works in the fully automatic segmentation of spinal CT images is presented here. For

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the spine [9], presents an algorithm which utilizes an edge detection function and region detection function to extract lumbar vertebrae for identifying disc herniation. This method is initialized with an Otsu threshold. The level set is formulated in terms of intensities by adding a weighted kernel to each pixel, as opposed to [10], where the edge stopping function is defined in terms of Euler Lagrange coefficients. Wu and Lin were able to identify dominant features in cervical vertebrae with a similar threshold-based initialization approach [11]. To overcome the inherent drawbacks of thresholding, an adaptive 3D region growing method is devised in [12]. A fully automated method of segmentation for delineating the thoracic and lumbar vertebrae is given in [13]. While it calls for seed placement in the canal, a level-set is allowed to evolve followed by a voxel-based delineation. Certain morphological operations are allowed to enhance the process. The use of atlas for aiding segmentation is an alternate method [14–16]. A three step algorithm is developed in [17] adopting Statistical Shape Models (SSM), that includes a seed placement, initial labeling and final optimization. This method is designed to handle complex geometry of all processes and variability between the individuals.

Shape prior models based segmentation of CT data for effective partitioning is presented in several articles. Gao and Chae employ the shape and intensity priors for segmenting tooth obtained from CT images [18]. The level sets are tracked based on initialization over a single slice while a boundary over each tooth has to be manually identified. Zhang et al. [10] proposed a new pressure force that isolates ROI for selective local or global segmentation. Nonetheless, the initial contour as an input from the user is essential. Local region characteristics have also been exploited in [19]. A distance driven active contour for CT segmentation is proposed by Truc et al. [20] which mainly focuses on segmenting the inhomogeneous structures. A convex combination of homogeneity and density steers the contour propagation. The authors report better results when compared to Chan-Vese (CV) model.

To segment the abdominal CT [21], Golodetz et al., use image partition forests to locate the contour with minimal or no intervention. It is imperative to furnish an initial partition, since each image sequence has a unique structure that requires the use of watershed and waterfall algorithms. Anatomical knowledge from the image aids to refine the forest and leads to a highly image specific segmentation method. Choi and Kim discuss the problem of extracting chest wall from chest CT data [22]. The method first learns from a given set of data and the parameters are tuned using Gradient Vector Field (GVF) algorithm. These input parameters are uniformly fixed for images that are subsequently segmented. An initialization-free active contour method is proposed in [23] for generic images that use radial basis function at its core level set. Its response on images with noise and artifacts are yet to be explored. The deterministic computational methods used in order to segment an image, deteriorate in the presence of noise. However, employing soft computing techniques like fuzzy logic can improve the performance [24–26]. Fuzzy rule based systems are built upon multiple combinations of thresholding.

Based on the membership associated with each cluster, segmentation results are achieved. For a known cluster sequence, the level set method is intertwined with the fuzzy concept. The fuzzy clustering is regarded as adaptive thresholding since the centroid of each class adjusts to the cost function [27]. Banerjee and Kundu propose a new technique to extract features in gray level images [28] keeping the basic assumption, that corner points are high curvature entities which lie on edges. Desired features are therefore obtained by identifying the intersection of ridges and valleys that constitute the corners. Also a fuzzy based membership is assigned to the dominant edges. The result benchmarked with those of deterministic methods like Harris and SUSAN is reported. A segmentation approach using fuzzy threshold for multi-region is formulated in [3] which uses a mapping between centroid of clustered pixels with a membership function. Madasu et al., developed a fuzzy edge and corner detector in case of color images using SUSAN corner detector as a base [29]. A fuzzified region based ACM method is presented in [27,30]. While a plethora of methods were developed for segmentation using ACM, limited attempts are accounted towards automatic initialization owing to its application constraint. For an efficient automatic method, it is crucial to detect feature points and edges even in the presence of noise and artifacts.

The present work is a novel technique that focuses on development of automatic contour initialization with fuzzy feature points while using the conventional ACM. Originality of the work manifests in the germination of initial contour which is directly associated with image features rather than a template or manual labor. A fuzzified corner metric based on image intensity is proposed to identify the feature markers which are enclosed by the contour. A concave shape approximating the boundary of these fuzzy corner points is obtained using α hull to provide initial contour for the ACM. Most of the existing methods are manual and face discrepancies in segmenting a stack of slices, while the proposed method will exploit the dearth in automation of such processes. The proposed method which is evaluated against conventional feature detectors and other generic initialization techniques, is found to perform robustly even in the presence of noise.

2. Methodology

This paper proposes automatic contour initialization for ACM based medical image segmentation. A set of feature markers from the image is extracted to construct an initial contour for the ACM. A fuzzified corner metric based on image intensity is proposed to identify the feature markers that are enclosed by the contour. A concave hull based on α shape, is constructed using these fuzzy corners yielding the initial contour which evolves due to the image forces. The segmented output is validated using similarity metrics computed from the ground truth segmentation performed by experienced radiologist. Functional block diagram of the proposed methodology is shown in Fig. 1. Novelty of the method rests in fuzzy-logic based feature point detection and contour initialization using α hull for ACM evolution. The subsections describe various methods involved in the scheme.

2.1. Active contour methods

ACM is a class of method that begins with an initial contour and evolves over a given time interval based on the internal and external characteristics pertaining to an image. The goal of geodesic active contour (GAC) or snake is to minimize the following energy,

$$E = \int_0^1 E_{int}(v(s)) + E_{img}(v(s)) + E_{ext}(v(s))ds \quad (1)$$

where

$v(s) = (x(s), y(s))$ represents the parameters of snake, $E_{int} = (\alpha(s)|\dot{v}(s)|^2 + \beta(s)|\ddot{v}(s)|^2)/2$ with α and β contributing for elasticity and

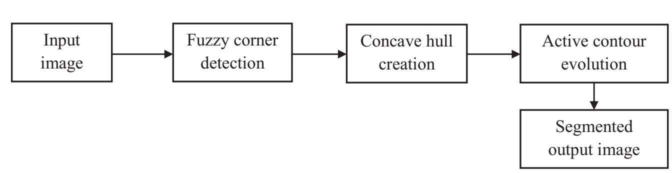

Fig. 1. Schematic of the proposed method.