COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 138 (2017) 1–12

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Individual tooth segmentation from CT images scanned with contacts of maxillary and mandible teeth

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ARTICLE INFO

Article history:
Received 31 January 2016
Received in revised form
13 August 2016
Accepted 4 October 2016

Keywords:
Computed tomography images
Tooth segmentation
Radon transform
Level set method
Mesh segmentation

ABSTRACT

Background and objective: Tooth segmentation from computed tomography (CT) images is a fundamental step in generating the three-dimensional models of tooth for computer-aided orthodontic treatment. Individual tooth segmentation from CT images scanned with contacts of maxillary and mandible teeth is especially challenging, and no method has been reported previously. This study aimed to develop a method for individual tooth segmentation from these images.

Methods: Tooth contours of maxilla and mandible are first segmented from the volumetric CT images slice-by-slice. For each slice, a line is extracted using the Radon transform to separate neighboring teeth, and each tooth contour is then segmented by a level set model from the corresponding side of the line. Then, each maxillary tooth whose contours overlap with that of mandible ones is detected, and a mesh model is reconstructed from all the contours of these maxillary and mandible teeth with contour overlap. The reconstructed mesh model is segmented using threshold and fast marching watershed method to separate the touched maxillary and mandible teeth. Finally, the separated tooth models are restored to fill the holes to obtain complete tooth models. The proposed method was tested on CT images of ten subjects scanned with natural contacts of maxillary and mandible teeth.

Results: For all the tested images, individual tooth regions are extracted successfully, and the segmentation accuracy and efficiency of the proposed method is promising.

Conclusions: The proposed method is effective to segment individual tooth from CT images scanned with contacts of maxillary and mandible teeth.

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http://dx.doi.org/10.1016/j.cmpb.2016.10.002

1. Introduction

Individual three-dimensional (3D) models of tooth are needed for the computer-aided orthodontic treatment planning and simulation [1]. Tooth segmentation from computed tomography (CT) images is a fundamental step in the modeling of tooth.

In the past decades, several methods have been proposed to segment teeth from CT images scanned while the subjects' teeth are in an open bite position where the maxillary and mandible teeth have no contact. These methods can be classified into two classes: 3D segmentation and two-dimensional (2D) slice-by-slice segmentation. The 3D segmentation methods directly segment tooth region in the 3D volumetric space. Akhoondali et al. [2] developed an automatic segmentation method based on region growing. Keyhaninejad et al. [3] and Hosntalab et al. [4] proposed to use 3D region based level set model to extract the tooth surface. Keustermans et al. [5] and Hiew et al. [6] applied a graph cut algorithm to interactively segment 3D tooth volume. Barone et al. [7] developed a novel framework to iteratively model the 3D shape of tooth with single-root from CT images. Instead of directly segmenting tooth from the volumetric images, they outlined the 2D contours of target tooth from a set of projected images, and the 3D tooth shape was modeled from these contours using a B-spline representation.

The 2D slice-by-slice segmentation methods segment tooth contours in each slice. This kind of methods generally applies the similarity of tooth intensity and/or shapes between adjacent slices to automatically initialize the tooth region, and the user only needs to manually initialize a starting slice. Heo and Chae [8] and Wu et al. [9] used the B-spline snakes with genetic algorithm to extract tooth contours. The B-spline snakes used in their methods cannot address the topological change of tooth contours. The level set method has been broadly used for the tooth contour segmentation due to its advantages in dealing with topological change and contour propagation [10–13]. Gao and Chae [10] proposed a level set model with shape and intensity prior to segment the tooth and achieved promising results. Yau et al. [11] applied the same model to extract the root contours. Ji et al. [12] modified this model to segment the anterior teeth. In our previous work [13], a hybrid level set model was developed for accurate root segmentation.

In orthodontics, the treatment not only needs to align teeth in each jaw, but also requires the teeth of maxilla and mandible to maintain correct occlusion condition. To check the occlusion condition, the dental CT images often needs to be scanned while the subjects' teeth are in a close bite position where maxillary and mandible teeth contact naturally. In these images, tooth contours of maxilla and mandible overlap in some slices of the occlusal contact area. The previous tooth segmentation methods are infeasible to extract individual tooth region from these images due to the missing boundaries between mandible and maxillary teeth. Wang et al. [14,15] proposed promising methods to segment maxilla and mandible from CT images scanned with contacts of maxillary and mandible teeth. However, there did not involve the individual tooth segmentation from alveolar bone.

The main contribution of this study is to develop a method for individual tooth segmentation from CT images scanned with contacts of maxillary and mandible teeth. The developed method first segments tooth contours from the volumetric CT images slice-by-slice using level set method. Then, each maxillary tooth whose contours overlap with that of mandible ones is detected, and a mesh model is reconstructed from all the contours of these maxillary and mandible teeth with contour overlap. The reconstructed model is segmented by threshold and fast marching watershed method to separate the contacted maxillary and mandible teeth. Finally, the separated tooth models are restored to fill the holes, and complete models of individual tooth are obtained.

The remainder of the manuscript is organized as follows. Section 2 introduces the background of the level set method and mesh model segmentation method. Section 3 presents the proposed individual tooth segmentation method. Section 4 shows the experimental results and discussions of the method, and the manuscript is concluded in Section 5.

2. Background of the level set method and mesh model segmentation

2.1. Hybrid level set model

The level set method is increasingly applied to medical image segmentation [16,17]. Recently, a hybrid level set model [13] was developed to segment tooth from CT image scanned without contact of maxillary and mandible teeth and presented excellent segmentation accuracy. The hybrid level set model is composed of a global intensity energy, a local intensity energy, a tooth shape constraint energy, and an edge detection energy. In this model, the global and local intensity energy are employed to address the topological changes and drive the curve move rapidly toward tooth boundary. The edge detection energy is integrated into the level set length regularization term to smooth and refine the localization of the curve. The tooth shape constraint term is used to constrain the tooth contour evolving toward the prior shape. The energy function of the hybrid level set model is expressed as follows

$$E(\phi) = (1 - w)E_{global}(\phi) + wE_{local}(\phi) + \beta E_{shape}(\phi) + \mu E_{edge}(\phi) \quad (1)$$

where ϕ is a 2D level set function, E_{global}, E_{local}, E_{shape}, and E_{edge} denote the global intensity energy, local intensity energy, tooth shape constraint energy, and edge detection energy, respectively; $\omega \in (0, 1)$, β, and μ are positive constants, representing the weight parameters of the corresponding energy term.

Let $\Omega \in \Re^2$ be the image plane, $I{:}\Omega \rightarrow \Re$ be the given gray image to be segmented, and Ω_1 ($\phi \geq 0$) and Ω_2 ($\phi < 0$) be the foreground and background regions, respectively, the global intensity energy is defined as

$$E_{global}(\phi) = \int_{\Omega} \log\left(\frac{p(I(X)|\Omega_2)}{p(I(X)|\Omega_1)}\right) H_{\varepsilon}(\phi(X))\,dx \quad (2)$$

where $p(I(X)|\Omega_i)$ ($i = 1, 2$) denotes the conditional probability of the intensity value $I(X)$ ($X \in \Re^2$), H_{ε} is the normalized Heaviside function [18]. The conditional probability $p(I(X)|\Omega_i)$ is estimated from the previous segmented slice.