A New Approach to Teeth Segmentation

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***Abstract*—Teeth segmentation is one of the important components in building an Automated Dental Identification System (ADIS). The extraction of the teeth from their corresponding dental radiographs is called teeth segmentation. Dental radiographs may suffer from poor teeth image quality, low contrast and uneven exposure that complicate the task of teeth segmentation. To achieve a good performance in segmentation, the teeth images are preprocessed by a two-step thresholding technique, which starts with an iterative thresholding followed by an adaptive thresholding to binarize the teeth images. Then, we propose to adapt the seam carving technique on the binary images, using both horizontal and vertical seams, to separate each individual tooth. The proposed method is evaluated experimentally and compared to other algorithms. The results show that our new approach achieves the lowest failure rate among all existing methods, and the highest optimality among all of the fully automated approaches reported in the literature.**

***Index Terms*— Teeth segmentation, preprocessing, binary image, horizontal and vertical seams, dental X-ray image.**

I. INTRODUCTION

A Automated identification of individuals is receiving increased attention. Fully automated image segmentation from different types of biometric images is an essential step for designing automated identification systems. In the context of Automated Dental Identification System (ADIS) [1] [2], teeth segmentation is an essential step to acquire the extent of teeth for identification of an individual. Teeth segmentation means partitioning a teeth image into its constituent regions and extracting each individual tooth. The segmentation of dental images is difficult due to the shape and intensity variations in X-ray images. Dental X-ray images are classified according to the view they are captured from and their coverage. The most commonly used images are panoramic, periapical, and bitewing. Panoramic is taken to view complete upper and lower jaws; it does not show fine details as bitewing and periapical do. Periapical is captured to obtain a view of the entire tooth area, including the tip of the root and the surrounding tissues. Bitewing is captured to view back teeth, only the crowns and parts of the roots for two to four adjacent teeth in both upper and lower jaws are captured. Bitewing images hold more information about the curvature and roots. There are several techniques proposed for teeth segmentation. Most techniques are devoted to develop a fully automated segmentation. Jain and Chen [3] proposed a semi-automated method based on integral projection and can be used with bitewing and panoramic views. Nomir and Abdel-Mottaleb [4] proposed an automated method based on iterative adaptive thresholding followed by an integral projection. It can be used for bitewing views. Zhou and Abdel-Mottaleb [5] proposed an automated method based on mathematical morphology followed by an integral projection which can only be used for bitewing views. Hajsaid et al [6] proposed another automated method based on mathematical morphology and can be used for both bitewing and periapical views. Nassar et al. [7] introduced evaluation criteria to measure the performance of different segmentation methods.

The bitewing and periapical images are the most common views made by dentists, and thus we work on these kinds of X-ray images. The paper is organized as follows: In Section II we present the preprocessing method, and the method for separating each individual tooth. In Section III the experimental results are presented, and finally, Section IV concludes the paper.

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II. RADIOGRAPH PREPROCESSING AND TEETH SEGMENTATION

Our teeth segmentation algorithm consists of three main components: preprocessing, horizontal and vertical seam carving, as shown in Fig. 1. In the preprocessing step we use the technique introduced in [8] which was adapted from [4]. This technique starts by applying an iterative thresholding followed by an adaptive thresholding to binarize the teeth images; we will give a brief description of the preprocessing step. Then, we propose to use a horizontal seam to separate the upper jaw from the lower jaw. For the third component, we propose to apply vertical seams to extract each tooth from their corresponding jaw (both the upper and lower).

A. Radiograph preprocessing

Segmentation in dental X-Ray images is a very challenging task because of the variations from image to image which are caused by discrepancy in the exposure. Moreover, deviations from one region to another within the same image increase the difficulty in teeth segmentation.

Typically, Dental X-Ray images have three different regions. The background, bone areas, and the teeth. Among these, background region corresponds to the soft tissues which has the lowest intensities, whereas bone areas and the teeth have the middle and highest intensities, respectively.

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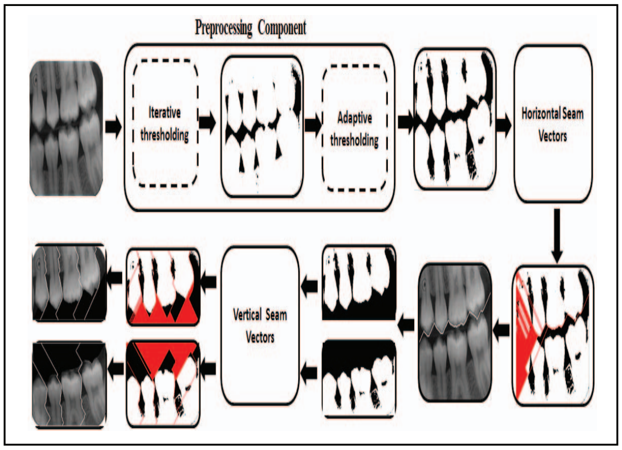

Fig. 1. Block diagram of the teeth segmentation process.

It is difficult to use a single threshold for the whole image because the intensities of bone areas are very close to the intensities of the teeth [6]. We used the technique introduced in [4] to pre-process the dental images which starts with an iterative thresholding followed by an adaptive thresholding introduced in [9] [10]. The purpose is to binarize teeth images adaptively.

First, edge detection is performed in an original image using the canny edge detector [11]. The resulted image is then processed by the morphological dilation to get the pixels around the location of edges [12]. Morphological dilation was performed by two flat structure elements each contains 3 neighbors, one in vertical and the other in horizontal direction. The average gray value of the corresponding pixels of the dilated image in the original image is used as the initial threshold. The iterative thresholding scheme starts with this threshold on the obtained dilated image. Then it is followed by the adaptive thresholding to obtain a binarized image. Adaptive thresholding actually changes the pixel's value at the center of a window according to the average gray value of the non-zero pixels inside this window. The technique is applied to each pixel to get a binarized image.

B. *Teeth segmentation*

Our proposed approach for teeth segmentation is based on the technique that was used for resizing digital images [13]. In this technique the energy of each pixel in the image is computed before resizing. A seam is a continuous series of pixels that is a connected path of low energy pixels in an image that can be either vertical or horizontal; a vertical seam is a path of pixels connected from top to bottom in an image with one pixel in each row; a horizontal seam is similar, except that the connection is from left to right. The energy indicates the importance of pixels. There are several energy functions, while the simplest is the image gradient magnitude.

After defining the energy of each pixel, lower energy pixels are removed or duplicated in order to decrease or increase the image size. In this paper, we compute the seam carving based on the energy functions of the pixel intensity value of the dental image that is a binary image obtained from the preprocessing step as described in Section II.A. So the energy function can take either 0 for the pixels in background region or 1 for the pixels in teeth region instead of the gradient as in [13].

We found that the seam carving technique cannot work well when applied to the original teeth image. The preprocessing step is essential for the seam carving method to work properly for our problem.

B.1. Separating the Upper and the Lower Jaws

The energy of a seam is defined as the sum of all pixels' energy in the seam. We use the dynamic programming technique that is also employed in [13] to look for the seam with minimal energy. In order to separate the upper and the lower jaws from their corresponding binary dental image, we first compute the horizontal seam by establishing the cumulative energy function matrix using the following equation:

$$M(x,y) = E(x,y) + \min\{M(x-1,y-1), M(x,y-1), M(x+1,y-1)\}$$

where $E(x,y)$ denotes the energy of the pixel located in the image at (x,y). This function considers the three possible paths to reach cell (x,y), i.e., horizontal, vertical, and diagonal. When (x,y) is on the edge, some of these directions may not be possible and they are omitted from the formula.

These cumulative energy functions are used for the dynamic programming algorithm to find the minimum cumulative energy path. In the case of a horizontal seam, the first step is to traverse the image from left to right and compute the cumulative minimum energy M for all possible connected seams for each entry (x, y), as shown in Fig. 2. (a).

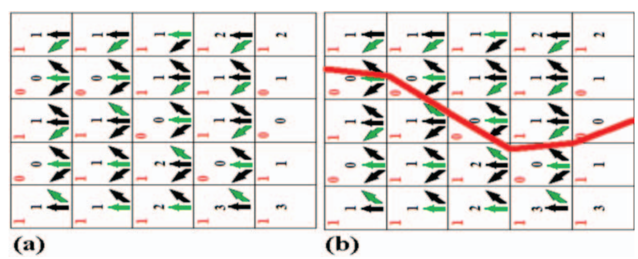

Fig. 2. (a) Each square represents a pixel, with the bottom-left value in red representing the energy value for that pixel. The value in black represents the cumulative sum of energies leading up that pixel. (b) Trace the seam from the last column by following the green arrows.

Then the pixel at last column is found in the cumulative matrix whose cumulative energy is minimum. Following this, we backtrack from this pixel to obtain an optimal horizontal seam that separates the upper and the lower jaws, as displayed in Fig. 2 (b) and Fig. 3.

B.2. Segmentation of Each Individual Tooth

To separate each tooth from either an upper or lower jaw, we use vertical seams which are similar to the horizontal seam used for separating the jaws. The goal is to find the seams that separate adjacent teeth in to individual ones. The energy of a seam is defined as the sum of all binarized pixels' values in the seam. We use the dynamic programming technique as we have done with horizontal seam to find the seam with minimum energy. In order to separate each tooth from its corresponding jaw (upper or lower), we compute the vertical seams by computing the cumulative energy matrix.

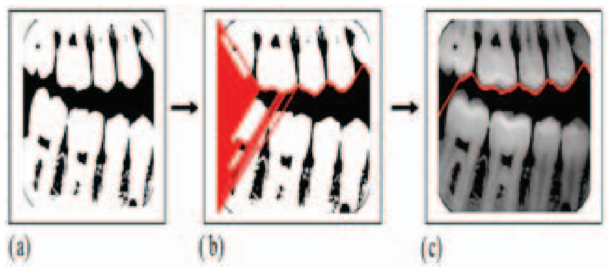

Fig. 3. (a) Result of adaptive thresholding; (b) Horizontal seams carving; (c) Separating the upper and the lower jaws.

The pixels in the cumulative matrix at last row, whose cumulative energy are minimal, are located. After performing this, we backtrack from these pixels to obtain optimal vertical seams (i.e. more than one seam that depends on the number of teeth per jaw) that separates adjacent teeth. Fig. 4 and Fig. 5 show the extraction of individual teeth from its upper jaw and the lower jaw, respectively.

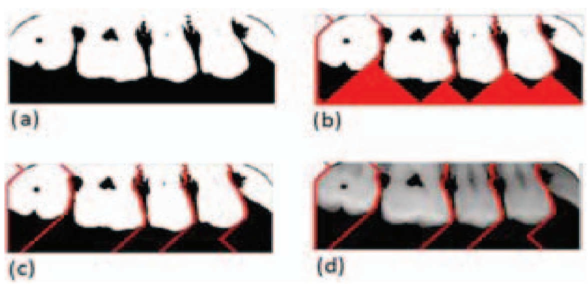

Fig. 4. Upper jaw: (a) A result of image pre-processing; (b) Vertical seams carving; (c) Detected separating lines; (d) Detected separating lines overlaid over the original image.

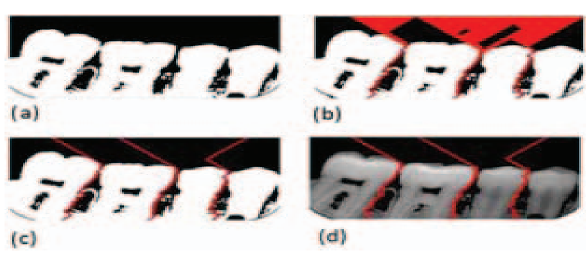

Fig. 5. Lower jaw: (a) A result of image pre-processing; (b) Vertical seams carving; (c) Detected separating lines overlaid over the preprocessing image; (d) Detected separating lines overlaid over the original image.

III. EXPERIMENTAL RESULTS

Our proposed segmentation technique was applied to two test sets of 500 bitewing and 130 periapical dental radiographic films selected from large dental radiographic databases [14] [15]. For the bitewing and periapical radiographic films, we obtained accurate segmented results in most images. A summary of the segmentation results is given in Table I. Some teeth segmentation/separation results are also shown in Fig. 6.

TABLE I
The segmentation results

	Bitewing		Upper Periapical	Lower Periapical
Total number of dental films	500		66	64
Total number of teeth	Upper jaw	Lower jaw	250	220
	1833	1692		
Number of correctly separated teeth	1604	1422	199	178
Ratio of correctly separated teeth	87.51%	84.04%	79.60%	79.56%

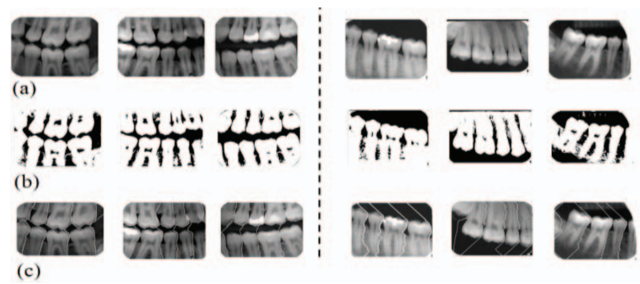

Fig. 6. Teeth segmentation and separation results; (a) the original images; (b) the images after pre-processing; (c) the detected separating lines overlaid over the original image.

Fig. 7 shows the comparison of teeth segmentation output from the two dental film (a, b) using state of the art algorithms [4,3] and our proposed method. It is clear that the segmentation results, (c, d), obtained with integral projection in [4], or the results, (e, f), obtained with a semi-automated method in [3], are not able to separate the teeth well. And also, the tooth separation does not fit tightly around the actual boundary of the teeth. However, the results, (g, h), obtained by our proposed method are significantly better and the regions of interest for most teeth are bounded tightly.

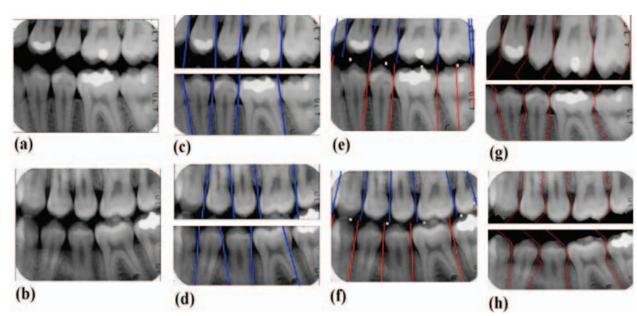

Fig. 7. Comparison of teeth separation results; (a,b) input images; (c,d) the detected separating lines overlaid over the original images by using algorithm [4]. (e,f) the detected separating lines by using algorithm [3]. (g,h) the detected separating lines by using our proposed algorithm. One can see that our method gives better teeth separations than those in [4,3].

To have a quantitative comparison, we use the performance evaluation methodology in [7], and compare the performance of our proposed method with the methods in [3] [4] [5] [6], using the same radiographic databases for the empirical assessment. Optimality rate and failure rate [7] are the two measures used to quantify the performance of the segmentation. The optimality rate is computed by the summation of product of the main diagonal with the corresponding total number of dental films in the scene, divided by the summation of the square of the total number of dental films used in testing. The failure rate is computed by the summation of product of the total number of incorrectly segmented of dental films with the corresponding total number of dental films in the scene, divided by the summation of the square of the total number of dental films used in testing.

All films in the bitewing radiographic set contain up to 10 teeth per film, and films in the periapical radiographic set contain up to 5 teeth per film. In counting the number of correctly detected teeth in a film, we visually inspect the outcome of segmentation for each film using a simple rule of tooth containment within each segment in a given film.

It is worth noting that, the bitewing set of dental images used in [3] [4] [5] [6] for testing is the same as the one used for testing our segmentation approach, and the periapical set of dental images used in [6] is the same as the one used for testing our segmentation method.

Testing results for the algorithm that we proposed for bitewing radiographic set and periapical set are summarized in Figs. 8 and 9, respectively.

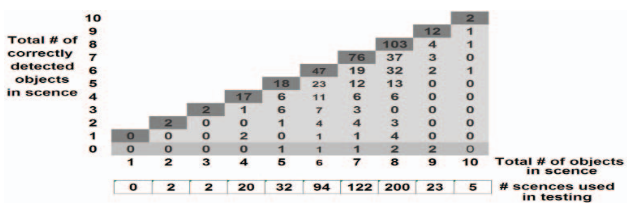

Fig. 8. Testing results for our teeth segmentation algorithm on bitewing views.

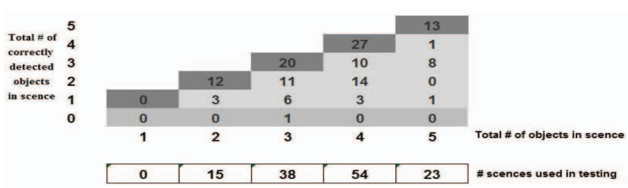

Fig. 9. Testing results for our teeth segmentation algorithm on periapical views.

We have obtained an optimality rate of 54.02%, which is superior to all existing fully automated dental segmentation algorithms in the literature, and a failure rate of 1.05%, which is the lower than any previous teeth segmentation algorithms in bitewing views. See Table II for details.

TABLE II
Comparison between the failure rates and optimality rates of the variant teeth segmentation algorithms with bitewing views

Algorithm	Our Algorithm	Hajsaid et al [6]	Jain and Chen* [3]	Nomir and Abdel-Mottaleb [4]	Zhou and Abdel-Mottaleb [5]
Failure rate	1.05%	1.27%	2.61%	11.18%	3.47%
Optimality rate	54.02%	14.96%	61.85%	19.24%	28.84%

* denotes a semi-automated dental segmentation algorithm.

For the periapical view, we have obtained a high optimality rate of 58.13% and a low failure rate of 0.74%, better than the 27.18% and 8.88%, respectively, obtained by Hajsaid et al. [6], which is the state-of-the-art automated teeth segmentation algorithm on periapical view.

IV. Conclusion

In this paper, we have presented a novel approach to teeth segmentation in dental X-ray images. The original radiograph images are preprocessed first by using adaptive thresholding techniques. Then, we developed a method based on adapting the seam carving technique on the preprocessed (rather than the original) images for teeth segmentation. Experimental results have shown that the performance of our new approach to teeth segmentation is significantly better than the state-of-the-art methods. In the future, additional post- processing techniques will be explored to further enhance the performance of teeth segmentation, and the influence of the segmentation results on teeth recognition will be evaluated.

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