A Novel Approach for Dental Panoramic Radiograph Segmentation

Georges Dibeh
Department of Physics and Electronics
Faculty of Science, Lebanese University
Beirut, Lebanon
georges.dibeh@hotmail.com

Alaa Hilal
Department of Communication and Computer Network Engineering
Faculty of Technology, Lebanese University
Aabey, Lebanon
alaa.hilal@ul.edu.lb

Jamal Charara
Department of Physics and Electronics
Faculty of Science, Lebanese University
Beirut, Lebanon
jcharara@ul.edu.lb

***Abstract*— Segmentation of dental panoramic radiographs is a critical element in a typical image analysis and understanding system such as in biomedical or biometric applications. It enables the detection and the classification of various components, including jaws, teeth, lesions and carries. However, available methods have demonstrated limited results due to the challenging complexity of the panoramic images. In this paper we propose a novel automatic segmentation method that separates maxillary and mandibular jaws with a shape-free model and distinguishes teeth using lines defined within a precise scheme. The developed approaches are implemented and tested over a database of dental panoramic radiographs. Obtained results demonstrate good performance and showed the suitability of the proposed method.**

Keywords: Dental Panoramic Radiograph, Dental X-ray Segmentation, Polynomial Regression, oblique line integrals.

I. Introduction

Dental X-ray radiography has been commonly used to find hidden dental structures, malignant or benign masses, bone loss, and cavities. Depending on the image acquisition process, radiographic images can be classified into intra-oral and extra-oral categories. Intra-oral category produces bitewing, periapical and occlusal images where the X-ray film/detector is placed inside the mouth. Whereas extra-oral category yields to panoramic, cephalometric and cone beam computerized tomography images where the X-ray film/detector is placed outside the mouth.

More specifically, dental panoramic radiograph (DPR) is a panoramic X-ray imagery that covers the entire dentition and surrounding structures, the facial bones and condyles, and parts of the maxillary sinus and nasal complexes. It can be seen as a form of focal plane tomography where images of multiple planes are taken to make up the composite two-dimensional panoramic image. An important application is being used in computer aided dental diagnosis systems (CADDS), where the digital DPRs are being analyzed for identifying caries [1] and lesions [2]. Another essential application is the use of digital radiograph in order to extract a discriminant signature used for postmortem identification (ADIS) purposes in biometric systems [3].

Independently of the application, teeth segmentation in the DPR is a major process in the block diagram of any image analysis-based system. It incorporates the separation of the maxillary and the mandibular jaws and then the localization of each tooth. An accurate segmentation will enable a better representation of the elements which is critical for sub-proceeding processes such as feature extraction and classification. Therefore, the segmentation results, among other processes, will be affecting the overall performance of the image analysis based system.

Among the challenges of DPR's segmentation are to overcome operator mistakes, operand movement and mal-positioning during the image acquisition process, account for teeth abnormalities as well as bad image acquisition conditions, such as low image contrast, uneven exposure, and severe skew. However, by reviewing the proposed methods in the literature, relatively few methods have been developed and adapted specifically to segment DPRs.

Depending on the shape model in which jaws or teeth are detected, we classify the segmentation methods into two categories. A first category of researchers has modeled the cavity between the upper and lower jaws and between teeth using straight or curved lines.

Anil K. Jain and Hong [4], proposed a semi-automatic segmentation method where the user needs to select the Region Of Interest (ROI) that contains the gap between the jaws to initiate a probabilistic model. The image is then divided into vertical strips and horizontal integrals are then used in each one for gap valley detection. A spline function is then used to find a smooth curve passing through the lines in each strip. They then sum the intensity of pixels perpendicularly to this curve to find the gaps between the teeth and straight lines are finally drawn [4]. The developed method has been applied over bitewing images.

Robert Wanat [5] modified Anil K. Jain and Hong's method [4], for panoramic images, into a fully automatic approach by choosing the horizontal integral projection with the lowest value, that is also close to the center of the image, usually between 40% an 60% of its height. The algorithm for jaw segmentation then continues as Anil K. Jain and Hong's method [4]. The curved line found is then translated over a limited range iteratively and pixel intensities along the line are detected, the iteration with a distinctive drop in intensities would be the region of dental pulp where dental necks are found. Considering the symmetry in each jaw eight gaps are then selected representing

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the gaps from the central incisors to the last molar tooth. Vertical lines are then drawn for non-molar tooth and a special algorithm is made for molar teeth. The main drawback in this method according to the authors is with teeth separation due to the weak approach.

Abdel-Mottaleb et al. [6], and J. D. Zhou and M. Abdel-Mottaleb [7] segmented bitewing images in similar approaches using straight lines. They used iterative and adaptive thresholding in order to segment the teeth from their background. However, in D. Zhou and M. Abdel-Mottaleb's method, the images are first enhanced by applying top-hat and bottom-hat morphological operators.

P. L. LIN et al. [8] firstly enhanced the image by subtracting it from its bottom-hat filtered transformation. Horizontal and vertical integral projection are then used within adaptive window for valley points detection. Refined curves are finally drawn to connect the valley points. The method has been applied over bitewing images. Ergun Gumus segmented panoramic images using discrete Wavelet transform and polynomial regression in order to separate the two jaws and using radial scanning for teeth separation with straight lines [9].

The second category of proposed methods does not incorporate any assumption over the shape of cavity between jaws or teeth. Instead a shape-free based segmentation is used. Said et al. [10] used morphological operators, labeling and filtering to segment teeth in bitewing and periapical images.

J. D. Zhou and M. Abdel-Mottaleb [11] used ROI localization with a modified snake contour for segmentation of bitewing images. Azam Harandi et al. [12] segmented the upper from the lower jaw of bitewing images using morphological operators and active contour. Pedro H. M. Lira & Gilson A. Giraldi [13] segmented panoramic images using mathematical morphology, quadtree decomposition for mask generation, thresholding and snake models. Abdolvahab Ehsani Rad et al. [14] segmented bitewing images using level set method.

The main drawback of the proposed methods in the literature can be summarized in two points. First, the segmentation model of cavity between jaws in panoramic images must be robust to noise and image artifacts. Therefore, a poor segmentation of jaws will directly affect the performance of the proceeding process, the teeth segmentation. The second drawback is that the proposed and implemented methods are not completely adaptable to panoramic images. More precisely, a major challenge while segmenting panoramic image is with overlapping and skewed teeth. In such cases vertical lines are not guaranteed to cross the gaps between the teeth.

In this paper, we propose and develop a novel segmentation method that accounts an adaptable specific model for the jaws and the teeth. The developed method is first presented in section II. Obtained results are presented and discussed in section III before finishing with conclusion in section IV.

II. Proposed Segmentation Method

In order to segment panoramic images, images are first pre-processed. Secondly, cavity between upper and lower jaw should be detected with a shape-free contour. This model would account for image artifacts, especially those related to the image acquisition process, and must still be robust to noise. Finally, as for the cavity between teeth, a scheme is proposed that accounts for a characteristic related to the panoramic image construction. These three main blocks of our segmentation method will be developed consecutively.

A. Image pre-processing.

DPRs are captured under a specific setup, where the patient's head is positioned using specific guides allowing the dental arc to fall within a focus region and the midline to be centered in the machine. Thus, the central incisors are almost positioned at the center of the image, the condyles about equal distance from the center and one third of the way down from the top edge of the image.

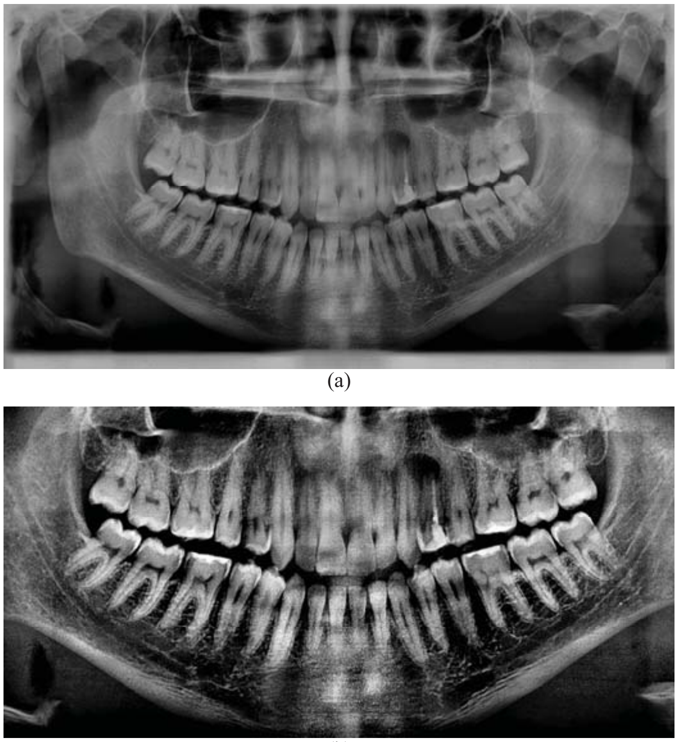
This setup is almost identical to all panoramic acquisition devices and would allow to automatically define a ROI that contains the teeth and excludes as much as possible the surrounding structures of the image such as the facial bones and parts of the maxillary sinus and nasal complexes. Therefore, DPR's are first cropped into a rectangular image that contains the ROI.

The ROI is next enhanced in order to better express teeth and increase local contrast in the image. As a fact, DPR's contains three main elements with distinct intensities, the teeth, the bones and the background. An appropriate image enhancement would darken the background while brightening the teeth. Therefore, the top-hat and the bottom-hat transformations of the ROI are calculated. A disk mask with the size of the standard deviation of pixel values in the initial image is used as the structuring element for both transformations. The ROI is then added to its top-hat filtered transformation and then subtracted from its top-hat filtered transformation. Result of ROI selection as well as enhancement is shown in figure 1.

B. Segmentation of maxillary and mandibular jaws

Dental panoramic radiography tries to project the teeth arch as orthogonally as possible while maintaining a constant distance between the teeth to the film and generator. In addition, it includes a process that re-constructs images of multiple planes in order to make up the composite panoramic image.

A first consequence is that the maxilla and the mandible are in the focal trough and the structures that are superficial and deep to the trough are blurred. A second more important consequence is that the horizontal plane separating the two jaws in the 3-D scene is expressed as a curve in the reconstructed image rather than a horizontal line. The region between the maxillary and mandibular jaws has a supplementary characteristic of being darker than the teeth above and below it.



(a)

(b)

Figure 1. Image pre-processing; (a) initial image (b) the ROI cropped out of the initial image and then enhanced.

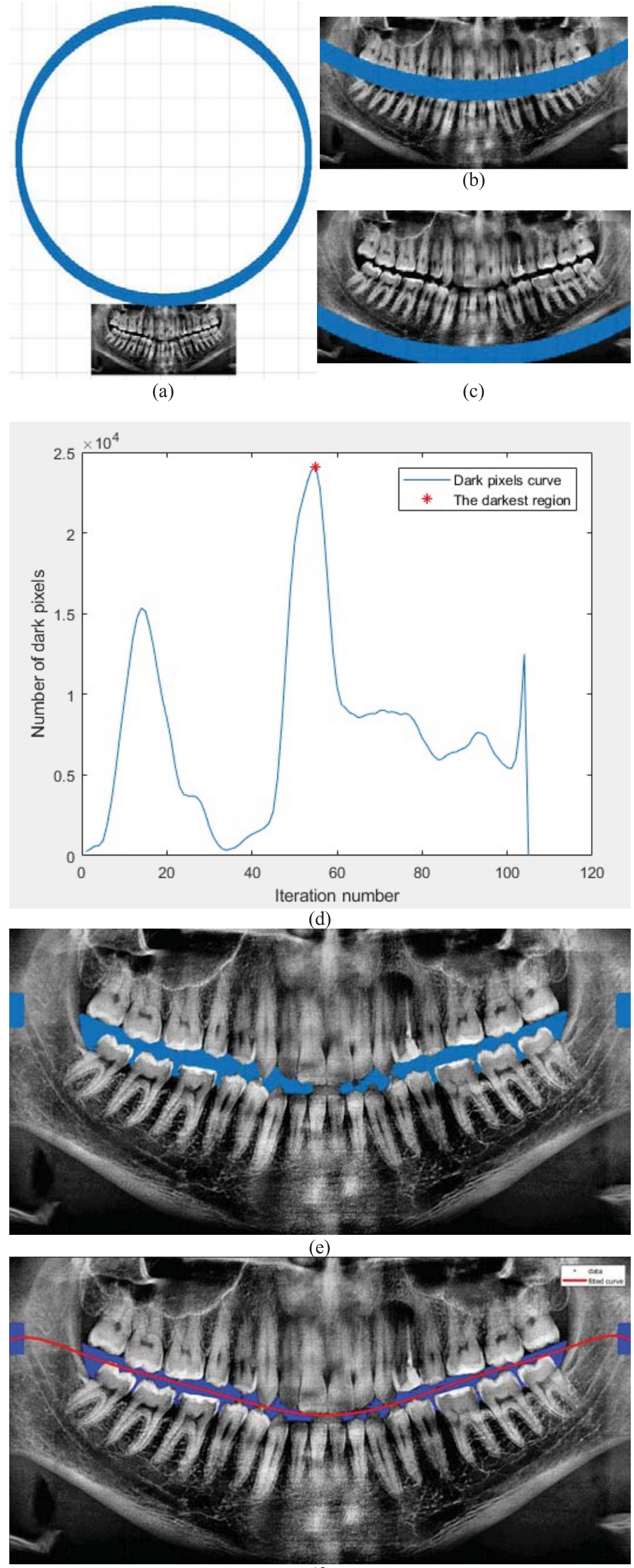
In our method, we detect seed points within this region by identifying the region with the maximum number of dark pixels using an arc-shaped mask. The arc has a width *d* and makes part of a circle of radius equal to the width of the image. The mask is placed such that the center of the circle it forms, moves over the vertical line perpendicular to the image and that passes through its center.

The mask is first placed at the top of the image (figure 2(a)) and then moved progressively toward the bottom of the image (figures 2(b), 2(c)). This is necessary in order to scan the complete image. At every step, the intensity profile along the mask is calculated and the number of dark pixel is counted. This refers to counting the pixels that have an intensity lower than a threshold intensity value *T* that must be tuned. Once the image is scanned, the region with the global maximum count refers to the space between the maxillary and mandibular jaws (figure 2(d) and 2(e)).

The correspondent pixels in the mask are then used as seed points for *N*-degree polynomial curve fitting. Least absolute residual method is used. The obtained fitted curve is shown in figure 2(e). It allows to separate the two jaws and consequently segment maxillary and mandibular teeth.

C. Teeth Segmentation

When considering the arc shaped mask performed in the previous section, the region in the maxillary image with the brightest pixel values would be the teeth thus allowing us to isolate the sinus region as shown in figure 3(a). The same applies for the mandibular image allowing us to isolate the neck region as shown in figure 3(d).



(a)

(b)

(c)

(d)

(e)

(f)

Figure 2. Segmentation of mandibular and maxillary jaws. (a), (b) and (c) an arc-shaped mask is used to scans the image starting from its top downward its bottom. (d) The frequency of pixels having an intensity lower than a threshold value, T, along the scanning are calculated. Global maximum is calculated and marked with a red star. It refers to the pixels, displayed in blue color (e) that separates the two jaws. (f) The seed points are finally fitted using a N-degree polynomial curve.

It can be seen from figure 3(a) that the space between teeth can be nearly approximated with straight lines excluding the cases of overlapping and skewed teeth. These lines tend to be vertical between teeth near the center of the image and rather oblique with increasing distance from the center.

Therefore, we model the space between teeth, as lines projecting from the center of a circle toward its perimeter. The center and radius of the circle correspond to the mask setup that detects the space between maxillary and mandibular jaws obtained in the previous section (figure 2(b), 2(d)). This setup would ensure that lines at the center of image are vertical while tending to follow the same image curvature as moving from the center.

In order to detect spaces between maxillary teeth. Lines are projected following the described setup all over the maxillary teeth ROI image. Two consecutive lines are separated with an angular resolution θ. Intensity profiles along line integrals are then calculated and summed for each line. Local maximums are then evaluated over the smoothed summed intensity profiles. These values correspond to regions within the teeth. Then the global minimum between each 2 consecutive local maximums is found as shown in figure 3(b). This would refer to lines, where each is passing between two consecutive teeth. A condition that ensures a minimum distance between two successive lines is added while searching for local maximums in order to decrease false detections.

The previous approach is applied in order to detect mandibular teeth. The global minimum detection process along line integrals is repeated while considering the mandibular image in order to detect lines that separate mandibular teeth. The obtained result is shown in figure 3(d).

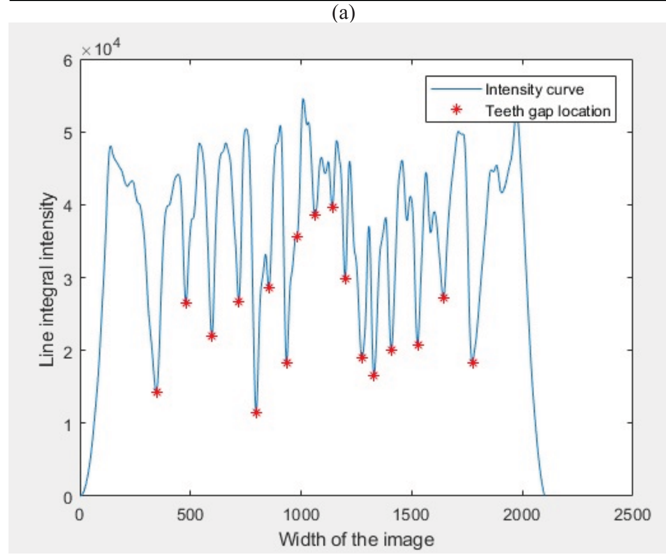
III. RESULTS

A database of 62 grayscale panoramic images is constituted. The images are obtained in JPEG format from three different radiography machines Vatech, Planmecca and NewTom with dimensions of 2868×1504, 2953×1435, and 2616×1569 pixels respectively [15][16][17]. They cover panoramic radiographs of male and female patients aged between 8 and 65 years.

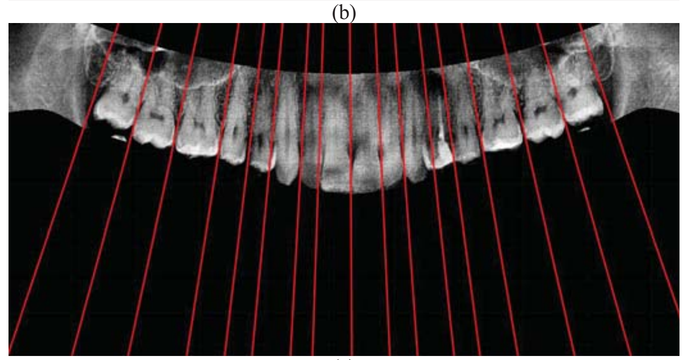
The proposed segmentation method was implemented under MATLAB software, and analyzed over the database. For a proper implementation, six values have to be tuned over the images of the database:

1) ROI coordinates for image cropping during pre-processing process: Images produced from the three radiography machines have the central incisors almost positioned at the center of the image, the condyles about equal distance from the center and one third of the way down from the top edge of the image. This would allow to properly define a ROI that corresponds to whatever image produced by the same machine. The ROI was selected as a rectangle centered at the same center of the image that spans from $1/4$ to $4/5$ the width as well as the height of the image as shown in figure 1(b).

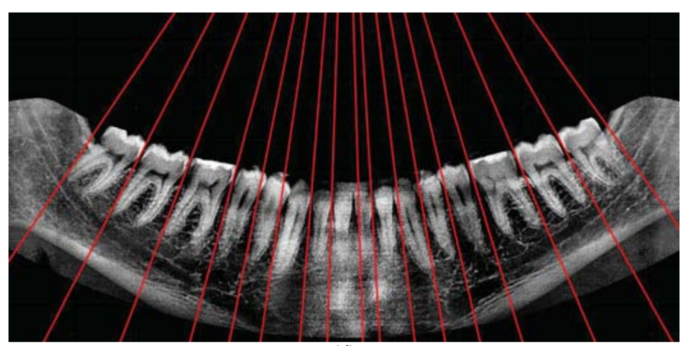
(a)



(b)

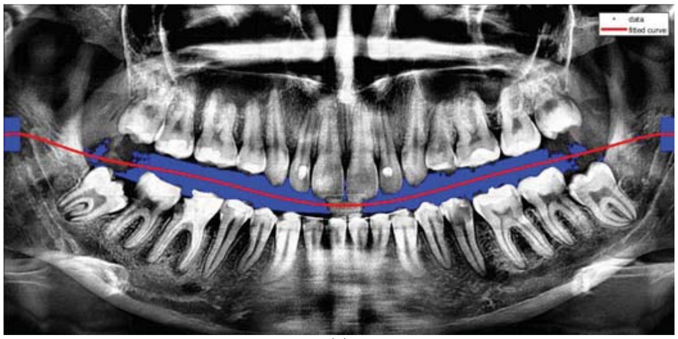


(c)

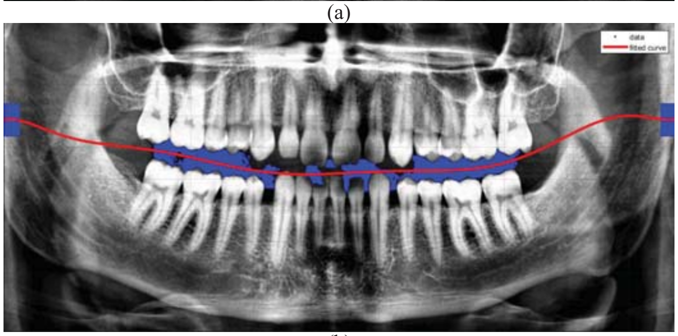


(d)

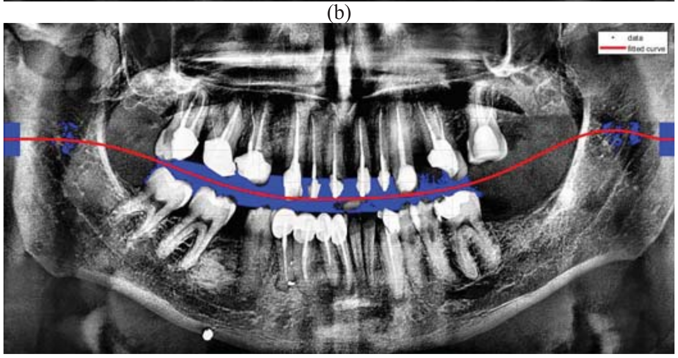
Figure 3. (a) Maxillary teeth ROI. (b) Sum of intensity values along lines integrals that scans maxillary teeth. X-axis refers to lines covering the image from its left to its right, the y-axis refers to the summed intensity value along each integral line. Star marks represent the global minimums which corresponds to lines separating consecutive teeth as shown in (c). (d) Separation of mandibular teeth under the same approach.



(a)



(b)



(c)

Figure 4. Detection and curve fitting of the space between the maxillary and the mandibular jaws displayed for three different images from the database.

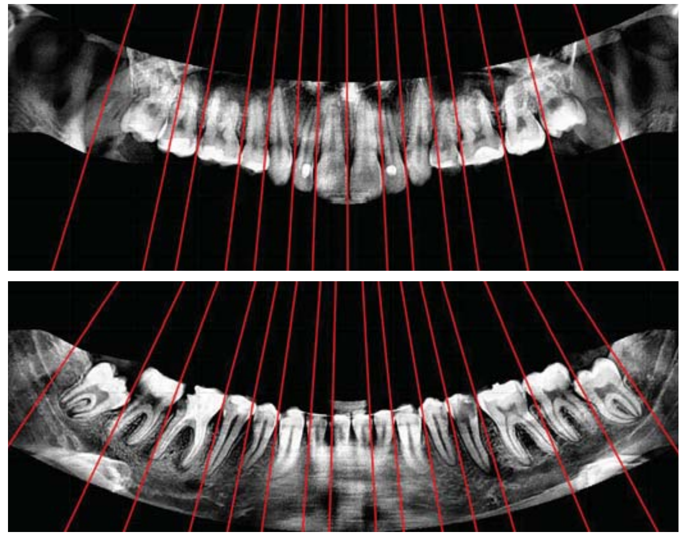
2) *Width of the arc mask, d:* This parameter corresponds to the width of the arc mask used during segmentation of maxillary and mandibular jaws. Its value was empirically fixed to $d = 100$ pixels.

3) *Threshold intensity value, T:* It refers to grayscale value used to detect seed points between maxillary and mandibular jaws. It was tunned to $T = 20$.

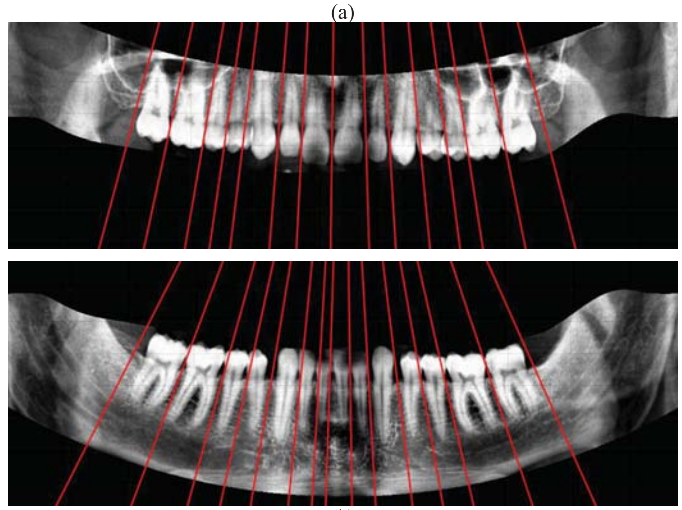
4) *Degree, N, of polynomial fitting curve:* After segmentation of maxillary and mandibular jaws is found, the detected seed points are fitted into a N-degree polynomial curve. Experimental testing showed that the degree $N = 9$ best fit the seed points over the images of the database and was consecutively used in the algorithm.

5) *Angular resolution θ :* The angle between two consecutive lines that scans maxillary and mandibular teeth is defined such that $\theta = 39.6^{\circ}/w$, where w is the width of the image

6) *Minimum distance between two local maximums during maxillary and mandibular teeth segmentation:* In order to minimize under- and over-segmentation, a minimum distance must be ensured between any two local maximums. This distance was tuned to 60 and 45 pixels while segmenting maxillary and mandibular teeth respectively (figure 3(b)).



(a)



(b)

Figure 5. Segmentation of teeth using oblique lines. Result over images in figure 4(a) and 4(b) are displayed in (a) and (b) respectively. The first and the second row of each part represents maxillary and mandibular teeth detection respectively. The images are manually cropped and contrast enhanced for display purposes.

The proposed segmentation method is applied over the database. Samples of the space detection between maxillary and mandibular jaws as well as their curve fitting is shown in figure 4. Localization of teeth are then performed. Results of teeth segmentation of images shown in figure 4(a) and 4(b) are displayed in figure 5.

The proposed segmentation method was properly able to locate and model the space between jaws even though when some teeth are missing as shown in figure 4(c). As for maxillary and mandibular teeth segmentation, it can be shown from figure 5, that the proposed model successfully segments the teeth in the majority of the cases. However, this model is limited with case of overlapping and skewed teeth as such as the mandibular teeth in figure 5(a).

The proposed method is seen to be robust to image noise and artifacts. In addition, the approximation of the space between teeth, is robust to dental filling that reflects as a bright intensity region over the teeth as shown in figure 4(c).

IV. Conclusion

The proposed automatic segmentation method segments the space between the maxillary and the mandibular jaws using a shape-free model that is fitted into a 9-degree polynomial curve.

Teeth are then segmented using oblique lines projecting from the center of a circle toward its perimeter. The center and radius of the circle correspond to the mask setup that detects the space between maxillary and mandibular jaws.

The obtained results show the robustness of the method to obtain an appropriate segmentation over image artifacts especially teeth filling, skewed and overlapping teeth.

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