

# A Problem of Automatic Segmentation of Digital Dental Panoramic X-Ray Images for Forensic Human Identification

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## Abstract

Dental radiographic images are one of the most popular biometrics used in the process of forensic human identification. This led to the creation of the Automatic Dental Identification System with the goal of decreasing the time it takes to perform a single search in a large database of dental records. A fully automated system identifying people based on dental X-ray images requires a prior segmentation of the radiogram into sections containing a single tooth. In this paper, a novel method for such segmentation is presented, developed for the dental radiographic images depicting the full dentition - pantomograms. The described method utilizes the locations of areas between necks of teeth to determine the separating lines and does not depend on the articulation of gaps between adjacent teeth, thus improving the results achieved in the situation of severe occlusions.

**Keywords:** image segmentation, dental pantomography, dental human identification, ADIS, forensic identification

## 1 Introduction

Automatic human identification has always been one of the main applications of pattern recognition. Various biometrics have been used as a basis for such identification, e.g. handwriting, iris, face, fingerprints etc. In reality, there exist situations where some of those biometrics can not be applied. Post-mortem (PM) identification, performed by experts in forensic medicine, consists in determining the identity of a deceased person. This undermines the ability to use some biometrics, such as handwriting or voice, but in some instances there might be other factors rendering other biometrics useless or impractical, for example face recognition in case of fire victims or DNA matching in case of mass natural disasters with multiple casualties. Dental characteristics are popularly used in forensics because of both their robustness to decomposition as well as the speed of a single identification([1]).

This led to the creation of the study of proper use of dental evidence in the judicial system - odontology.

The abundance of dental data in criminal cases inspired the Federal Bureau of Investigation (FBI) to create a separate Dental Task Force (DTF) in 1997 ([2]). Its primary task was to create a database to store dental images, known as the Digital Image Repository (DIR), and an automated system for human identification based on the existing Automated Fingerprint Identification System, named Automated Dental Identification System (ADIS). The goal of the system is to provide the ability to narrow the search for an individual in the DIR by automatically finding a small number of the most similar X-ray images. This speeds up the process of a single identification, as out of a large database of images only a small number of comparisons needs to be performed by a forensic expert. The model and functionality of ADIS were presented in [3]. Unlike an identification procedure performed by an odontologist, where artificial dental restorations, such as fillings and dentures, are used as a basis of comparison ([4]), the approach taken in ADIS focuses on teeth morphology and uses teeth contours extracted from dental radiograms in the process of matching.

The simplified model of ADIS assumes three preliminary steps before the comparison: image enhancement, image segmentation and feature extraction ([5]). The first step focuses on improving the contrast of the image, which is usually of low quality. The second step, image segmentation, separates the image into disjunctive segments, each containing at most one tooth. The last step, feature extraction, detects the shape of the contour of a tooth, if present on a given segment, and saves the result in a form that will later be used in the comparison process. While there exist numerous approaches to each of the preliminary steps for intraoral images (i.e. photographs taken with the x-ray film situated inside the patient's mouth, thus showing only a fragment of his dentition), few approaches have been developed for panoramic extraoral images (i.e. photographs taken with both X-ray tube and film moving on an arc on the opposite sides of the patient's head, thus showing the full dentition). Panoramic images, or pantomograms, convey the largest amount of information of all types of

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Figure 1: A sample pantomogram after image enhancement and cropping.

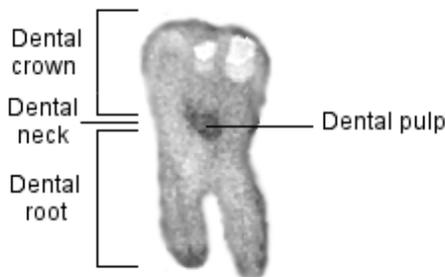


Figure 2: The locations of the parts of a tooth used in this paper.

dental radiographic images because they show the widest range of dentition. The main drawback of this method is that it causes severe occlusions in the resulting image, because it renders a semicircular geometry of the jaw onto a 2-dimensional image. A sample pantomogram that will be used to demonstrate every step of the described method can be seen on fig. 1. All pantomograms in this paper are presented courtesy of Pomeranian University of Medicine in Szczecin.

In this paper, a novel method for image segmentation of a panoramic dental radiogram is proposed. Unlike the previously existing methods for separating intraoral images, the presented method uses two easily localizable points, one between the necks of teeth and one between the roots of teeth (the parts of a tooth mentioned in this paper are shown on fig. 2), in order to determine a straight line delimiting the areas of successive teeth. The method was created to be used with panoramic images only, so it employs features that might be unavailable on intraoral images and should not be utilized with them. Experimental results of the proposed method are also presented on a small sample of radiograms to demonstrate its effectiveness in real world application.

## 2 Previous work

As has been mentioned in the previous section of this article, there are several existing methods of dental radiogram segmentation. Most of these methods have been created with intraoral images in mind and do not work well with pantomograms.

The first method was presented by Jain and Chen in [6]. It focuses on using integral projections of pixels to detect gaps between teeth. The algorithm is separated into two parts: the first is the detection of the gap between lower and upper jaw, the second is the detection of gaps separating individual teeth. The former step needs user input, so it can be considered semi-automatic. After the initial point of the gap has been selected by the user, moving in both directions, the algorithm chooses short horizontal lines with the highest probability of belonging to the gap. The probability is calculated using (1):

$$p(v_i, D_i) = p_{v_i}(D_i)p_{v_i}(y_i), \quad (1)$$

where  $p_{v_i}(D_i)$  is the normalized integral projection of a given horizontal line subtracted from 1 and  $p_{v_i}(y_i)$  is a Gaussian with expected value equal to the position of the last chosen line (or the user selection in the first iteration). This probability function has its maximum for the horizontal line that is vertically close to the last selected line and that is composed of pixels with low values. After the maxima have been found for the whole image, a spline function is used to form a smooth line that becomes the separating line between upper and lower jaw. Once the spline has been calculated, for every point on the curve a new integral projection is calculated in the direction perpendicular to its local curvature. These projections assume low values in areas between teeth, thus the search for gaps can be reduced to searching for valleys in the plot of the integrals. The areas between these three lines (gap between upper/lower jaw, two successive gaps between teeth) and the horizontal borders of the image become the segments used later in the process of feature extraction.

The initial tests of this approach revealed that it is not sufficient for separating teeth on pantomograms. The proper operation of this method requires the presence of strongly emphasized dark regions between teeth. This requirement is frequently not upheld in the case of panoramic radiograms. During the research it was determined that in multiple cases integral projections can have lower values in the areas around the middle of a tooth than in the areas on the edge of the tooth, although this situation does not occur on the exemplary radiogram. It happens especially when there are dental fillings on any single side of the tooth or two teeth occlude with each other, creating an area with a heightened radiopacity that increases the integral projection value. Another problem that arises when using the integral projections method is that using the direction perpendicular to the local curvature of the line separating the upper and lower jaw as the slope of a line separating two teeth is only possible with perfectly aligned

teeth, but malaligned teeth can not be separated using this method. While these two shortcomings are not as problematic in the case of intraoral images, their combination resulted in a large amount of mis-segmented images in the database of pantomograms used in this study.

A partial solution to the first problem described in the previous paragraph was presented in [7]. In the case of the lack of strongly emphasized dark regions between teeth the image needs to be processed in order to accentuate the slightly darker regions. 2-dimensional wavelets composed of two 1-dimensional filters were used in [7] to draw out these regions. Based on whether a low-pass filter or high-pass filter was used in each direction, different results are named LL, LH, HL and HH, with the first letter indicating which filter was used horizontally and the second letter indicating which was used vertically. An LH filter is used before the upper and lower jaw separation, while an HL filter is used before the detection of vertical lines separating individual teeth. The segmentation itself is performed using the integral projections.

The last described method, presented in [8], consists of the use of active contour models, also known as snakes. Initially described in [9], snakes are a model of parametrized splines driven towards edges and lines on the image by external forces, i.e. forces derived from the image on which they operate, as well as internal forces, i.e. user imposed control over the elasticity and rigidity of the contour. In [7], a snake used for the segmentation of the image is defined as a parametrized curve  $v_s = [x(s), y(s)]$ ,  $s \in [0, 1]$  with its energy calculated using (2):

$$E = \int_0^1 \left( \frac{1}{2} \alpha |v'(s)| + \frac{1}{2} \beta |v''(s)| \right) + E_{ext}(v(s)) ds, \quad (2)$$

where  $\alpha$  and  $\beta$  are the weight parameters allowing control of the snake's tension as well as rigidity and  $E_{ext}$  is the external driving force along the contour of the snake, given in [8] as (3):

$$E_{ext} = G_{\sigma}(x, y) I(x, y), \quad (3)$$

where  $G_{\sigma}$  is a 2-dimensional Gaussian and  $I(x, y)$  is the original image. Thus defined external force amounts to the Gaussian-filtered original image, in which case it takes the lowest values in the dark areas of the picture, such as the gap between upper and lower jaw or in spaces between teeth. With properly selected initial approximations of these curves and weights  $\alpha$  and  $\beta$  it achieves very good segmentation of the image.

The main reason why this approach does not provide the expected results for pantomograms is the same as one of the reasons as to why the previous method was discarded, i.e. severely occluding teeth render it inutile. Dependence on the articulation of gaps between teeth hinders the correctness of the outcome of this method, as a simple Gaussian-filtered image in many cases does not contain distinct enough areas between teeth to ensure a proper segmentation and currently no external force function has been developed to allow for driving the snake in the proper

direction in that situation. It should also be noted that snakes work slower than the integral projections, as the initial curve is iteratively improved and both the first- and second-order terms need to be recalculated after every iteration. This issue becomes more pronounced in larger databases, where an additional second added to the calculation time for a single tooth in a small set of 100 images results in almost an additional hour needed for calculation. The last problem stems from the influence of the initial approximation on the final result. No method for selecting the initial curves was presented in [8] and the basis of such selection is not trivial. A preliminary search for the gaps between teeth needs to be conducted before the snakes can be used to separate them and the end result relies on the success of this step.

## 3 Presented method

### 3.1 Preliminary steps

To our best knowledge, there are no segmentation methods created explicitly for pantomograms, and the shortcomings of the existing methods encouraged the development of a new approach. It is assumed that before a picture is segmented using the following method, it was enhanced using the method presented in [10]. That method is based on the decomposition of the image into a Laplacian pyramid (that is, a set of images containing down-sampled differences between two consecutive layers of a Gaussian pyramid), separating the radiogram into smaller images containing progressively lower frequencies of the signal present in the original image. Then, a range of simple filters is applied to selected layers of the pyramid, including sharpening filter and contrast enhancement methods, before the image is recomposed again. The resulting image has a higher contrast than its original with a slightly increased noise. It is also necessary to locate the gap between the frontal teeth before the segmentation. In this paper a nose position detection is used and then a vertical line on the same position is considered the center, but any other method that provides a valid enough approximation can be used.

### 3.2 Separating the upper and lower jaw

The first step is the determination of the line separating the upper and lower jaw. The same method as presented in [6] and further described in the previous section is used. In order to automatize the process of segmentation, instead of requiring that the user inputs the initial separating point used by the algorithm, it is selected by choosing the horizontal integral projection with the lowest value, that is also close to the center of the image, usually between 40% and 60% of its height. Because the teeth on the picture create an arc, instead of using the full horizontal line that would pass through teeth further from the incisors, only a small

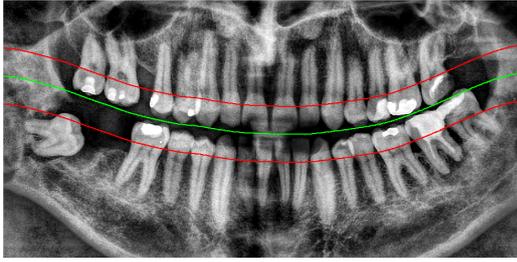


Figure 3: The splines passing through the dental pulp and indicating the height on which the necks of teeth can be found (outer lines) and the spline separating upper and lower jaw (middle line).

number of pixels (equal to 20% of the width of the image) closest to the previously selected frontal teeth gap is used to calculate the projections. Afterwards the algorithm proceeds as described in [6].

### 3.3 Localization of the areas between the necks of teeth

The obtained curve is then used to estimate the position of the neck of every tooth, which is the part of the tooth where roots end and the formation of crown and enamel begins. While the crowns of separate teeth tend to occlude with each other and roots are difficult to separate from the underlying bone, the area between the necks of two adjacent teeth is distinguishable enough to be easily found on a pantomogram. Because the necks of teeth are usually on the same height as dental pulp, which is darker than the surrounding teeth, the simplest and fastest method to find a line going through dental necks is to translate the line separating upper and lower jaw vertically, sum the intensities of pixels the line passes through for every translation and select the ones for which there is a distinctive drop of values, indicating the line passes through darker areas of the pulp. This is similar to the integral projections method, but the sums are not calculated along a straight horizontal or vertical line, but instead along a curve that is of identical shape as the spline separating upper and lower jaw and translated vertically. Thus calculated curves for the sample image are shown on fig. 3. In order to make sure neither the original gap between jaws nor a gap between roots of teeth and the edge of the image are selected in lieu of the desired dental pulp line, the vertical translation scope should be chosen to conduct the search for a limited range, automatically discarding translations too close and too far from the line separating jaws. The results of this step are two values, one negative and one positive, that indicate the amount of pixels that the vertical position of every point belonging to the spline separating jaws should be moved for in order to receive the spline that passes through dental pulps of teeth in each jaw.



Figure 4: An inverted original image multiplied by range-filtered original image. The size of the neighborhood taken into account during range filtering is 51x51 pixels.

The next step is the selection of points on each spline representing a gap between the necks of two adjacent teeth. To refine the results of this stage of the algorithm, a new image is created by multiplying the value-inverted original image with local range filtered version of the original image. That image has high values for darker pixels that lie in areas with neighboring points of low and high intensity. The larger the neighborhood used for calculating the range filter, the more distinct those areas become on the obtained image. The resulting image for the sample pantomogram is shown on fig. 4. For both upper and lower jaw, an array of values is saved containing the intensities of points belonging to the splines passing through their respective dental pulps. Sharp spikes on the plot of these values indicate dark spots surrounded by light regions, indicating a gap between necks of teeth. To remove false spikes, the values are Gaussian filtered to smooth the function. Then, starting from the previously selected line separating frontal teeth, small subsets of the values in the array are chosen for comparison. To determine the size of these subsets, average widths of teeth on every position were calculated based on twenty sample pantomograms. Both jaws are fairly symmetrical considering the size of teeth on a given position, thus only eight values need to be calculated for each jaw, one for every tooth from first incisor to last molar.

To ensure that the chosen subsets are wide enough to contain both smaller and larger teeth on a given position, the array values on distances from the previously selected gap ranging from 75% to 175% of the average tooth size are considered as possible positions for the gap. To select the proper spike among these values, for every value in the subset, its closest values are subtracted from it and the results are summed to form a distinction function. This function is then normalized and multiplied by a Gaussian, much like in equation (1). The Gaussian has an expected value based on which direction the algorithm is moving in in a given moment, considering the gap between frontal teeth. The expected value is always chosen to lie in the point indicating the average width of a tooth on the currently searched position, thus if the algorithm is moving

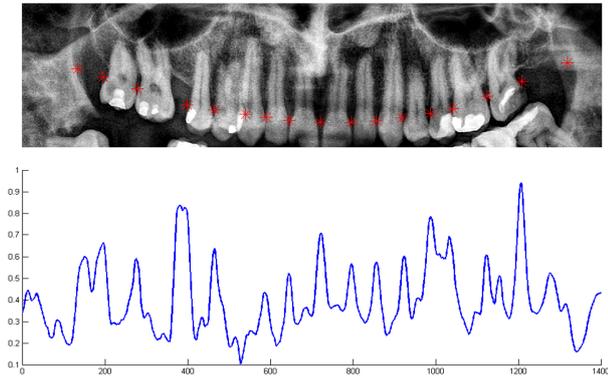


Figure 5: The upper jaw of the exemplary pantomogram with gap locations marked as stars. The plot below shows the intensity values of pixels through which the dental pulp line passes on the image presented on fig. 4, which is searched for spikes indicating gaps between teeth.

left and the chosen subset lies in the distance from  $-175\%$  to  $-75\%$  of the average tooth width from the previous gap, then the expected value needs to be chosen in a point that is  $-100\%$  of the average crown width from the previously selected gap. The function received by multiplying the distinction function and the Gaussian is considered to be the probability function that a given point is the new gap. The argument maximum of that function becomes the new gap position and the beginning point for the next iteration of the algorithm. It works separately for each part of the jaw, i.e. upper left, upper right, lower left and lower right. The algorithm searching for gaps in a given part stops when it has reached the vertical edge of the picture or if it has located eight subsequent gaps, indicating all teeth on that side were found. The results of this step of the algorithm are presented on fig. 5.

Thus calculated gap locations provide a good estimate of the position of areas between teeth. However, in some cases a simple vertical line is not enough to separate two adjacent teeth. Molars and, in some cases, premolars require an additional step of the algorithm to determine the angle of the segmenting line. In order to find a straight line separating these teeth, an additional point needs to be found between them. A simple greedy algorithm was used, iteratively moving 1 pixel towards the top or bottom of the picture, choosing the pixel in horizontal vicinity with the highest intensity on the inverted and range-filtered image and using it as the basis for the next iteration. After the number of iterations equal to half of the length of an average tooth on a pantomogram, the position of the last result becomes the second separating point and the line passing through gap between necks of teeth and the second separating point becomes the segmentation line. The drawback of this approach of finding the second separating point is that the roots of the tooth need to be distinctive enough from the background and neighboring teeth, so using that algorithm with incisors and canines usually produces in-

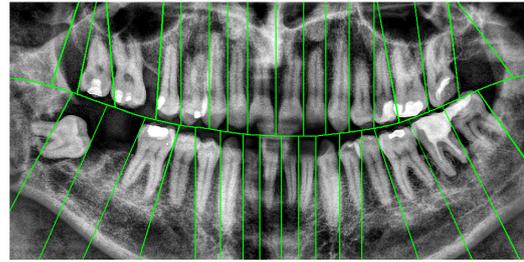


Figure 6: Lines separating individual teeth on the pantomogram. Simple vertical lines are used for incisors and premolars, while rotated lines achieved by determining two points between the teeth are used for molars.

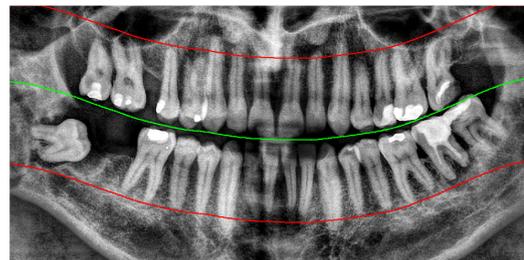
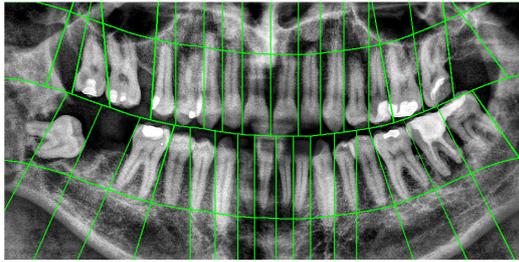


Figure 7: The splines that determine the end of roots (outer lines) and the spline separating upper and lower jaws (middle line) on which they are based.

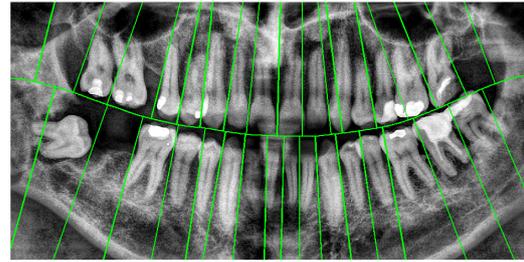
correct results. The separating lines acquired using this algorithm on a sample pantomogram are presented on fig. 6.

### 3.4 Removing the areas below the roots of teeth

The last step is to remove the areas below the roots of teeth. The method used to detect where teeth end is similar to detection of dental pulp line, i.e. the curve separating both jaws is translated vertically in search of an alignment where the sum of pixels it passes through is lower than the surrounding results, indicating the area between the teeth line and the cheekbone line was achieved. The only difference between this part of the algorithm and the search for the line of necks of teeth is the range of translations considered in the search. The results achieved using this algorithm to determine the curve separating teeth from areas below roots are presented on fig. 7. After finding these separating lines, every segment of the picture lying between four curves (jaws gap line, two consecutive lines separating adjacent teeth and the line below the dental roots) is considered an area possibly containing a tooth and can be later used in the process of feature extraction.



(a)



(b)

Figure 8: A comparison of the result of the proposed method (8(a)) and an another popular method used in the segmentation of dental radiograms - integral projections (8(b)).

## 4 Results and discussion

The above described method was tested on a database of 218 pantomograms, each sized 1500x800 pixels, and some exemplary results are presented in this section. Firstly, fig. 8 shows a comparison of results achieved for the proposed method and the integral projections method. The proposed method offers better results with more compact segments and less segmentation lines passing through the areas of teeth. It should also be noted that while the calculation of the plot shown on fig. 5 takes less than 1 second, the calculation of the integral projections in every point of the jaws separation curve takes 212 seconds on the same computer.

Some additional test results can be seen on fig. 9. If the teeth can be separated using a single line, the algorithm is usually able to find the optimal line of separation. The described method is also able, in some cases, to separate unerupted or not fully erupted teeth, as can be seen on fig. 9(c). The obvious bad results can be found in cases of occlusions so severe that it is impossible to find a straight line to separate both teeth, such as in the case of the incisor and the first premolar (respectively third and fourth tooth from the center of the image) of figures 9(a) and 9(e). Malaligned teeth can also be separated to a degree, but in the case of severe problems in alignment the separating line can not capture the whole tooth within a segment, for example the furthestmost bottom left molar in figure 8(a). Two neighboring dental fillings can also be problematic, as they are the brightest areas of the image and blend easily, making it impossible to decide where one tooth ends and the second begins (like the molars in the lower right region of figure 8(a)). Detection of the ends of dental roots helps in removing bright areas of the underlying bone that would be otherwise attributed to the tooth, but in some cases a fragment of the tooth is removed too, like on figure 9(e). The last problem stems from the fact that dental pulp can easily be mistaken for the edge of the tooth, resulting in a mis-segmentation. This happens in the case of the lower left incisor (third tooth) on figure 9(b), where the separating line passes through the middle of the tooth, but because average teeth widths are used, the next two teeth

segments are wider and the final eighth tooth is separated correctly.

## 5 Conclusions and future work

In this paper a novel method for segmenting dental panoramic radiograms into regions containing single teeth was described. It uses a different approach than the existing algorithms developed for intraoral images, focusing on detecting gaps between necks of teeth and roots of teeth, that are both easy to find on a pantomogram and allow to separate teeth even in the situation of occlusions. The presented method works fully automatically and with speed comparable to methods developed for intraoral images.

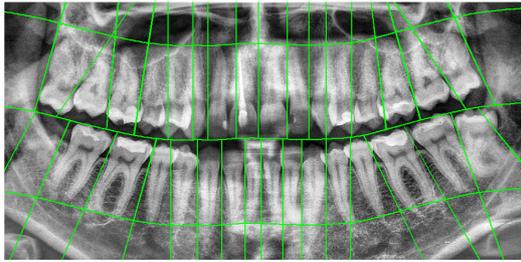
A considerable improvement of its results could be achieved if a more sophisticated method was used instead of the greedy algorithm to determine the second point through which the separating line between two teeth is traced. The method could also be used as an initial step for further segmentation with methods such as active contours to provide improvement of the results. Finally, the process of removing the areas below the roots of teeth could be conducted separately for every tooth instead of for all teeth in a jaw simultaneously, thus reducing the amount of root fragments incorrectly segmented outside of the tooth area.

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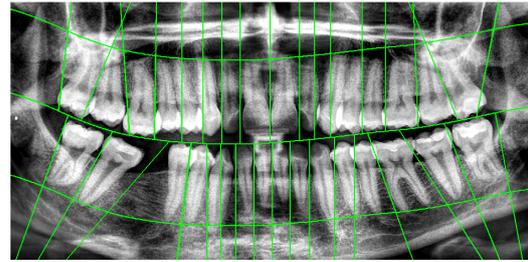
I would like to thank my parents for their continuous and discrete support during the writing of this article.

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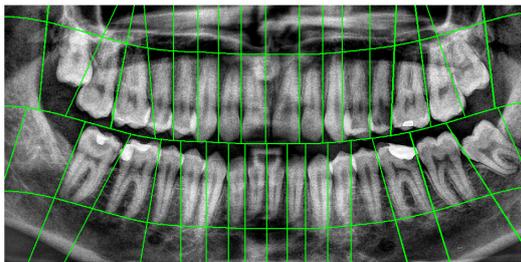
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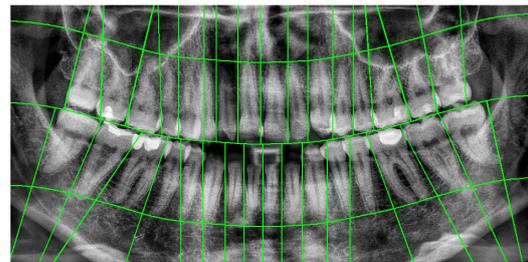
(a)



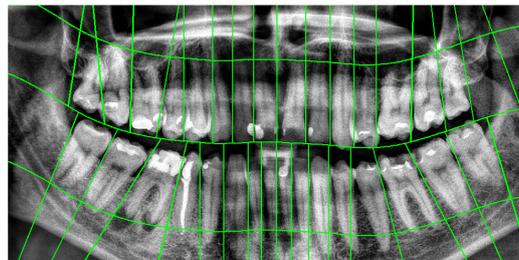
(b)



(c)



(d)



(e)

Figure 9: More exemplary results of the proposed method.

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