LETTER

Automatic Molar Extraction from Dental Panoramic Radiographs for Forensic Personal Identification

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SUMMARY Measurement of an individual molar provides rich information for forensic personal identification. We propose a computer-based system for extracting an individual molar from dental panoramic radiographs. A molar is obtained by extracting the region-of-interest, separating the maxilla and mandible, and extracting the boundaries between teeth. The proposed system is almost fully automatic; all that the user has to do is clicking three points on the boundary between the maxilla and the mandible.

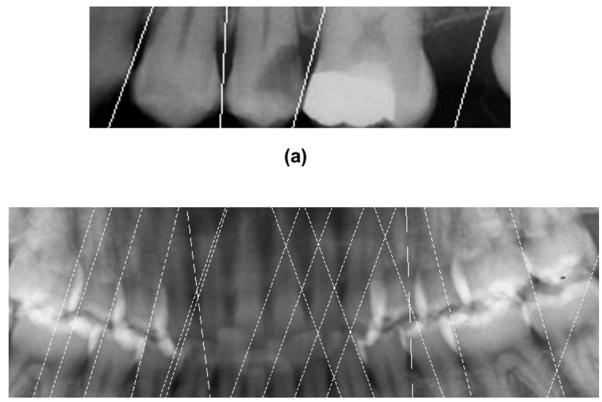
key words: *tooth extraction, dental panoramic radiographs*

1. Introduction

Dental radiographs are being used more often as the medium of choice for forensic personal identification [1]. Many features can be extracted from dental radiographs and used together to compose better discriminators. Another supporting factor is their survivability. Unlike other body tissues, teeth usually resist early decay. Thus they are the best candidates to identify victims under severe circumstances, such as those encountered in mass disasters, for example airplane crashes, and identification in the postmortem attempted some weeks after the death.

The identification is carried out by separating each individual tooth, extracting features by measuring the separated teeth, and comparing the features from a postmortem dental record to those from a database of antemortem records [2], [3].

There are several attempts to automate the process [1], [4], [5], since a huge number of images have to be processed in mass disasters. These methods separate each individual tooth by calculating projections along the direction from the crown to the tip of a tooth and finding boundaries between neighboring teeth. This method is effective for bitewing radiographs since the distortion of tooth shapes is small in this case. It is not applicable, however, to panoramic radiographs, since the shapes are highly distorted, as shown in Fig. 1.



(a)

(b)

Fig. 1 Segmentation by a conventional method [1]. (a) Bitewing radiograph. (b) Panoramic radiograph.

Since the panoramic radiograph views the mandible and the maxillae completely, it is usually taken for diagnosis and treatment of dental diseases [7]–[9]. It is also easily attainable even for a corpse. Thus a tooth separation method applicable to panoramic radiographs is necessary.

To apply the segmentation and separation methods for forensic personal identification, the region of interest containing teeth and surroundings tissue should be extracted from a raw radiograph, and the residual part should be removed. In conventional research, the region of interest is still extracted manually by an expert [4], [10].

In this paper, we propose a new system for acquiring molars, which are mainly used for the measurement and identification, from a raw dental panoramic radiograph. We already proposed a new fully automated system [6] for acquiring the region of interest by extracting a periodic structure of the arrangement of teeth by applying a spatial filter. Our new system separates the maxilla and the mandible withing the region of interest and the molars are extracted from them. The performance of our system is demonstrated by an experiment.

2. Methods

To extract a tooth from a raw dental panoramic radiograph image, we employ a three-step method illustrated in Figs. 2 and 3. The first step intends to select the region of interest, the second step will separate the image into maxillae and mandible, and the last step will extract the tooth from

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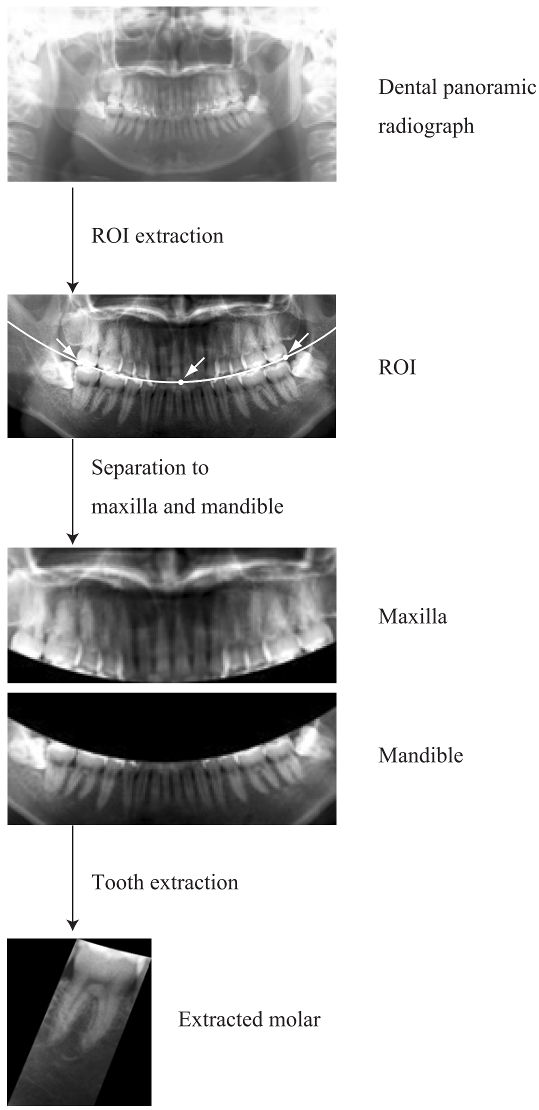


Fig. 2 Schematic diagram of the proposed method. The manually dotted points and the esimated boundary between the maxilla and mandible are indicated on the ROI image.

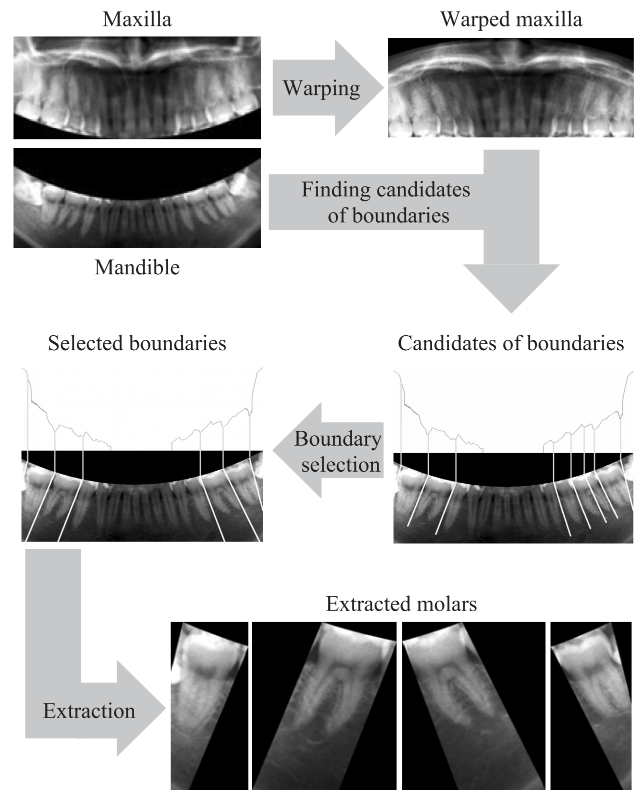


Fig. 3 Tooth extraction procedure.

maxillae and mandible.

2.1 Region-of-Interest Extraction

The method to extract the region-of-interest used here is what we proposed in [6]. The method is briefly explained in the following.

The method consists of the following two steps. The first step roughly extracts the tooth region as a rectangle by applying vertical and horizontal projections and finding the difference between those of the tooth region and the outside. The second step refines the region using a spatial filter. The image is converted to the two dimensional frequency domain using Fourier transform, and the outside bandwidth filter is applied to extract the periodical structure of the tooth arrangement. The stopband of the outside bandwidth filter employed here is between 2% and 98% of the highest frequency.

2.2 Separation of Maxilla and Mandible

To separate the maxillae and mandible, we utilize a user assisted mechanism. In this step, the user is required to supply three points on the boundary between the maxilla and mandible on the image. The system calculates the parabolic curve connecting these points using the least square method. This curve is regarded as the boundary between the maxilla and mandible.

2.3 Tooth Extraction

The final step extracts individual teeth. This step consists of the following two substeps.

2.3.1 Finding Candidates of Tooth Boundaries

We employ a method combining the vertical projection method and the minimal path detection method to extract the boundary between adjacent teeth. The region to detect is at first limited by applying the horizontal projection and extracting the region where the value of the projection is higher than a threshold.

A dental panoramic radiograph is usually captured with holding the patient's forehead and chin stably to ensure the proper positioning. In this case, the tooth arrangement on the radiograph tends to spread from root to crown in maxillae and the roots are sometimes grouped within a very narrow distance. If the displacement from the proper position is large enough to cause such a large distortion that this tendency in maxillae does not appear, the image of the teeth is not obtained since the teeth cannot be included in the tomographic layer of the panoramic dental radiography system. This tooth arrangement makes very difficult to separate the teeth. To increase the accuracy, the image is warped prior to the separation using the forward image mapping [11] combined with overwarping prevention method. The overwarping prevention method is as follows:

- For the lowest non-zero pixel in each vertical line in the image, the normal line of that pixel to the parabolic curve estimated in Sect. 2.2 is calculated.
- The angle of warping at each of the vertical line is calculated using the forward image mapping method.
- If the absolute difference between the warping angle of the vertical line and the normal line of the pixel is more than 10°, the warping angle of that vertical line is set to 10°.
- The line is warped into the new location using the forward image mapping method.

Since the tooth arrangement in mandibles is opposite to that in maxillae at the proper positioning, the intervals of the roots in the mandibles are large enough to be separated. Thus the warping is not necessary for the mandibles.

Following to the above warping, the vertical projection is applied to integrate the pixel values along the vertical lines. To increase the accuracy, the area to be integrated is limited vertically to the region between the horizontal line at the middle of the image height and that at 10 pixels above the bottom of the image. The profile of the vertical projections is smoothly traced by the minimal path detection method [12], and the curves as shown in Fig. 4 is obtained. The local minima on the traces are regarded as the positions of tooth boundaries.

The following adaptive selection method is applied to remove insignificant local minima faultily detected as boundaries:

- An n-pixel line segment connecting two points on the curve is assumed at each point. n regarded as minimum width of the tooth.
- The gradient of each line is calculated.
- The gradient is scanned from left to right. If the gradient of a segment is negative while that of the previous segment is positive, the point in the middle of the current line is selected to be the boundary.

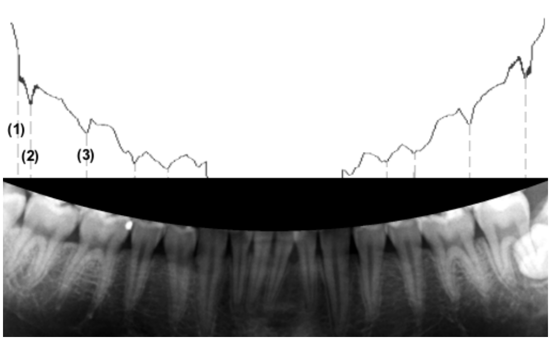


Fig. 4 Traces of the vertical projections and local minima selected as tooth boundaries. The solid and dashed lines indicate the resultant curve and points selected as boundaries, respectively.

2.3.2 Boundary Selection

The accuracy of the method in Sect. 2.3.1 is not perfect and some estimated boundaries are crossing the tooth. Thus the following boundary selection method is employed to select correct boundaries. The boundary selection method is based on the idea that the distance between two adjacent boundaries should be larger than the minimum width of a tooth. The algorithm is as follows:

- The estimated boundaries are scanned from left to right. A boundary is selected and the distance to the next boundary is calculated. In case of Fig. 4, the local minimum (1) is selected.
- If the distance is less than a threshold that is set to the minimum width of the molars, the nearest boundary where the distance is larger than or equal to the threshold is selected and all the boundaries between the selected two boundaries are removed. This boundary is regarded as the second boundary. In case of Fig. 4, the local minimum (3) is selected as second boundary.
- The distance to the previous boundary is calculated from the second boundary.
- If the distance is less than the threshold, the rightmost boundary on the left of the previous boundary where the distance between them is larger than or equal to the threshold is selected. This boundary is set to the first boundary again. This step is necessary to eliminate possibilities that more than one tooth are selected between the first and the second boundaries. In case of Fig. 4, the local minimum (2) is selected as the first boundary and the local minimum (1) is ignored.
- The latter selected boundaries, the local minima (2) and (3) in Fig. 4, are regarded as the selected boundaries, and the process is repeated until all the boundaries are processed.

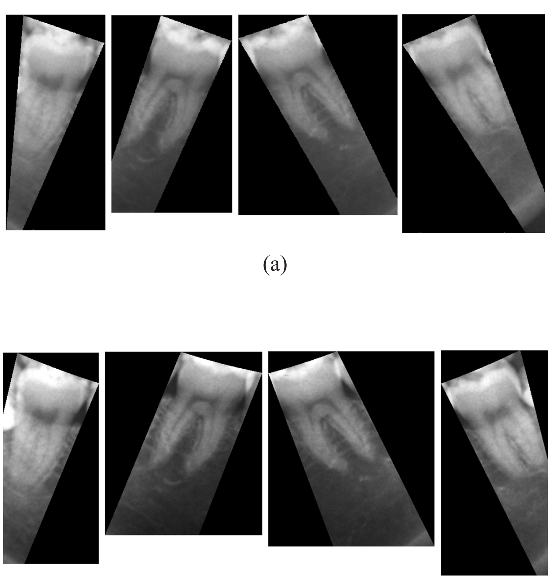
3. Experimental Results

We carried out experiments on 30 dental panoramic radiographs that were taken at the proper positioning. According to the requirement of the application to forensics [1], [2] the extraction can be regarded successful if at least one molar is extracted from each side of the maxilla and mandible.

The performance of this method is evaluated by the ratio of the number of extracted molars by this method to the number of molars extracted manually. The extraction of a

Table 1 Experimental results. The abbreviations "maxi." and "mand." indicate "maxilla" and "mandible," respectively.

Image No.	# of molars manual		# of molars automatic (proposed)		# of molars automatic (conventional)	
	maxi.	mand.	maxi.	mand.	maxi.	mand.
1	4	4	4	4	1	0
2	4	3	4	2	1	0
3	4	4	4	4	1	0
4	4	4	4	4	1	1
5	4	4	3	4	1	0
6	4	4	4	4	0	1
7	4	4	4	4	0	0
8	4	4	4	4	0	0
9	5	6	5	5	0	0
10	4	4	4	4	1	1
11	6	4	6	4	1	1
12	4	4	4	4	0	0
13	5	4	5	4	2	0
14	5	4	5	3	2	0
15	4	4	4	4	3	1
16	4	4	4	4	2	1
17	3	4	3	4	1	1
18	4	3	4	3	2	0
19	4	3	4	3	2	0
20	3	4	3	4	1	0
21	4	4	4	4	2	0
22	4	4	4	4	2	1
23	4	4	4	4	2	1
24	4	4	4	3	2	0
25	4	4	4	3	2	0
26	5	5	5	5	2	1
27	4	4	4	4	2	1
28	4	4	4	4	2	0
29	4	4	4	4	2	1
30	4	4	4	4	2	0
Total	124	120	123	115	42	12
Grand Total	244		238		54	
Accu-racy			98%		23%	



(a)

(b)

Fig. 5 Examples of resultant images. (a) Manual extraction. (b) Automatic extraction by the proposed method.

tooth is regarded to be successful if the whole of the target tooth is extracted and the extracted region of the adjacent teeth is less than a half of them. The experimetal results are shown in Table 1, and some examples of the resultant images are shown in Fig. 5. It shows that this method completely satisfies the criterion in forensics described above, and the accuracy of this method is 98%. The failures occurred in the case where adjacent molars were overlapped, or in the case where the boundaries were invisible because of metal covers on the molars.

4. Conclusions

We have proposed an automatic molar extraction method for dental panoramic radiographs. The experimental result shows that the performance of this method is very high and successfully satisfies the criterion for applications in forensics. We are now working on the application of this method for forensic personal identification by measuring and classifying the extracted molars.

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