An Effective Tooth Isolation Method for Bitewing Dental X-Ray Images

PO-WHEI HUANG\(^1\), PHEN-LAN LIM\(^2\), CHUN-HUNG KUO\(^3\), Y. S. CHO\(^1\)

\(^1\)Department of Computer Science and Engineering, National Chung-Hsing University, Taichung, Taiwan, ROC
\(^2\)Department of Computer Science and Information Engineering, Providence University, Shalu, Taichung, Taiwan, ROC

E-Mail: powhei.huang@msa.hinet.net, lan@pu.edu.tw

Abstract:

Tooth isolation is a very important pre-processing step for both computer-aided dental diagnosis and automatic dental identification systems. The accuracy of tooth isolation will directly affect the accuracy of feature extraction and thereby the final results of both types of systems. This paper presents a very effective and fully automatic tooth isolation method for bitewing dental X-ray images. Our upper-lower jaw separation mechanism is based on gray-scale integral projection to avoid possible information loss and incorporates with angle adjustment to handle skewed images. In single tooth isolation, we propose an adaptive windowing scheme for locating gap valleys to improve the accuracy. Furthermore, excessive isolation-curves can be removed and separating lines can be added to indicate the locations of missing teeth. Experimental results show that our method achieves higher tooth isolation accuracy rates for both upper- and lower-jaw images, when compared to Nomir and Abdel-Mottaleb’s method.

Keywords:

Bitewing dental radiograph, Tooth isolation; Isolation-curve verification, Missing-teeth detection, Adaptive windowing

1. Introduction

Biometrics is an identification technology for uniquely recognizing individuals based on measuring the subject’s physical or behavioral traits, such as fingerprints, iris, face, and voice [1]. However, most of these traits are not suitable for postmortem (PM) identification, when the victims are encountered in mass disasters or under severe decay of soft tissues. Teeth, being the hardest and most impregnable part of human body, are thus regarded to be the best candidate for PM identification due to their survivability and diversity [2]. In Automated Dental Identification System that was developed for PM identification, both shapes and sizes of teeth play important roles [3-7]; meanwhile in Computer-Aided Dental Diagnosis System, small and early lesions can better be detected from each individual tooth [8]. Thus, dental radiograph (X-ray image) segmentation is an essential step for achieving high accuracy of the subsequent stages for both types of systems. The first step of dental radiograph segmentation is to divide each tooth into a block such that each block contains only a tooth, and such step is generally known as tooth isolation. Since dental radiographs often suffer from poor quality such as low contrast, uneven exposure, severe skew, etc., or they may contain excessive dental works and occlusive teeth, tooth isolation of dental radiographs is thus a very challenging task.

Several good progresses had been made for tooth isolation in the past few years. Jain and Chen [5] proposed a “semi-automatic” method by using gray-scale integral projection and the maximum likelihood. They first obtain the horizontal integral projection of the image and find the positions of all valleys in the projection array. Assuming the user estimates an initial position of the gap valley, they then obtain the position of the gap valley by finding the one among all located valleys that has the maximum probability of being the gap valley. The horizontal line plotted from the position of the gap valley is regarded as the upper-lower jaw separation line. A similar method is used for finding all teeth separations in both the upper- and lower-jaw images. Nomir and Abdel-Mottaleb [6] presented a “fully automated” approach for a thresholded binary image using integral projection also, where the threshold is obtained using iterative thresholding. However, useful information may be lost due to imperfect thresholding which results in invalid findings of gap valleys in vertical integral projection, where the integral values are smaller than the preset threshold. Thus, over-segmentation or under-segmentation may occur, especially for images with uneven illumination or excessive dental works. Zhou and Abdel-Mottaleb [7] presented a method by using morphological operations for image enhancement as well as integral projection and snake (active contour model) for tooth isolation. Similar to the problem mentioned for the method in [6], they also search for valleys which have integral values smaller than the preset threshold for gap valleys in the vertical integral projection, and use them for setting the initial snake for each isolation curve. Although teeth are much emphasized with respect to the background, the method may still suffer from...
information loss due to imperfect thresholding, which can lead to over- or under-segmentation.

The remainder of this paper is organized as follows. In Section 2, a related work on tooth isolation is described. In Section 3, the proposed tooth isolation method including image enhancement, upper-lower jaw separation, single-tooth isolation, isolation-curve verification, and missing-teeth detection is described. Experimental results are provided in Section 4. Finally, the conclusions are given in Section 5.

2. Tooth isolation Method of Nomir and Abdel-Mottaleb

Nomir and Abdel-Mottaleb [6] presented a tooth isolation method for a thresholded binary image. Their method can be described from the following three steps: iterative thresholding, separation between the upper and the lower jaws, and isolation of each individual tooth.

Iterative thresholding

At first, Canny edge detector is used on the image to detect all edges. Then, morphological dilation is applied to the detected edge pixels. In general, half of the pixels in the dilated binary edge image will belong to the teeth areas and the other half will belong to the background and the gums areas. Therefore, the average gray value of the corresponding pixels from the image is used as an initial threshold $T_0$.

For each step $i$, the image is segmented using threshold $T_i$ into teeth areas and background areas, and a new threshold $T_{ni}$ is computed as the average of two mean gray values obtained from teeth areas and background areas, respectively. The procedure is repeated until $T_{ni} = T_0$.

Separation between the upper and the lower jaws

Assuming that a horizontal or near horizontal line with an angle $\theta$ that could be used as an approximation for separating the upper and the lower jaws exists, this separating line can be obtained by using horizontal projection as follow.

Let $I_B(x, y)$ be the $m \times n$ binary image after iterative thresholding, the horizontal (y-axis) integral projection

$$H(y) = \sum_{x=1}^{m} I_B(x, y)$$

is obtained. Since a gap usually exists between the upper and the lower jaws, the y-axis projection histogram will form a valley. Thus, the separating line at the position $y$ with the minimal value of the y-axis projection histogram can be regarded as the best line to separate both jaws.

However, it is not always the case that the separating line between the upper and the low jaws is horizontal due to the view variation when the radiographs are captured. The image is thus rotated by an angle $\theta$ in a range of [−20°, 20°], and the separating line is regarded as the best separating line if

$$ \left( \theta, y \right) = \arg \min_{(\theta, y)} H^\theta(y) $$

(2) where $H^\theta(y)$ is the horizontal integral projection obtained by rotating the binary image $I_B(x, y)$ with an angle $\theta$.

Isolation of each individual tooth

The method to isolate each tooth into a block is similar to the method used for separating the lower and upper jaws. For the upper (lower) image, the vertical (X-axis) integral projection

$$V(x) = \sum_{y=1}^{n} I_B(x, y)$$

(3) is obtained, where $n_i$ is the intersecting point of each column and the horizontal separating line. The gaps between the neighboring teeth cause valleys in the projection array, thus the vertical separating lines can be drawn at the location of gap valleys, which are defined as $V(x) < 35\%$ of the maximum $V(x)$. Since teeth do not always grow vertically or in the same direction, the vertical lines drawn at the positions of all the gap valleys may not well separate each tooth from its adjacent ones. Thus, the image is rotated by an angle $\theta$ in a range of [−20°, 20°], and all gap valleys of each $\theta$-rotated image within this angle range are located. Assuming the number of gap valleys is the same for all rotated images and the number of rotated images is $m$, then $m$ sets of gap valleys are obtained, where each set is from a $\theta$-rotated image. The best location of the gap between each pair of teeth is the position of the gap valley that has the minimum projection value among $m$ projection values of the same gap, and the separation-line for this gap is drawn at the location of the best gap valley at an angle $\theta$, where $\theta$ is the rotated angle of the image producing the best gap valley.

3. Our Proposed Tooth Isolation Method

Our proposed tooth isolation method contains horizontal (upper-lower jaw) separation, vertical (single-tooth) isolation, isolation-curve verification for over-segmentation, and missing-teeth detection for under-segmentation. Since dental radiographs always suffer from problems like noise, low contrast, and uneven exposure, images are enhanced before performing tooth isolation.

3.1. Image Enhancement

Many image enhancement methods for dental radiographs, such as adaptive intensity stretching, top-hat morphological transformations, and homomorphic filtering, etc., have been presented in literatures [3,7]. For tooth isolation purpose, images are better enhanced in such a way that the
intensities of teeth areas are much higher than the rest of the image and the intensities of the rest of the image are near equally dark.

The bottom-hat operator, defined as

$$E_{\text{Image}} = \text{Image} - \text{bottom_hat}(\text{Image}, \text{SE})$$

where $SE$ is a circular disc structuring element with its radius = $1/4$ of the image width.

Figure 1(c) shows the enhanced image of Figure 1(a). Notice that background, (missing) interdental papilla, and darker gum parts in the enhanced image all become much darker and the teeth areas become much brighter, when compared to the original image.

3.2. Horizontal (Upper-Lower Jaw) separation

Assuming that a horizontal or near horizontal line with an angle $\theta$ that could be used as an approximation for separating the upper and the lower jaws exists, such separating line can be obtained by using horizontal projection histogram as follows.

At first, we take integral projection of each horizontal line

$$H(y) = \sum_{x=1}^{m} I(x, y)$$

where $I(x,y), x=1, ..., m, y=1, ..., n,$ is the gray level intensity of the pixel at position $(x,y)$ of the image $I$, as shown in Figure 2(a).

Adopting the definition of “gap valley” as the valley in the integral projection formed by the gap between the upper and the lower jaws [5] and the concept of best angle search for skewed radiographs [6,7], we rotate the image by an angle $\theta$ in a range of $[-20^\circ, 20^\circ]$ at an interval of $0.5^\circ$ each, and take the horizontal integral projection for each $\theta$-rotated image $H'(y)$. We then find the “desired gap valley” using Eq. (3). Figure 2(a) shows the horizontal separation line of the image rotated by $-8^\circ$.

Notice that the separation line in Figure 2(a) still does not separate both jaws perfectly, because the third pair of teeth in the upper and lower jaw is occlusive. Thus, adopting the strip-windowing scheme in [6], we use the horizontal separation line obtained from the above procedure as a base line and set up a series of strip windows (length=70, width=20) centered at points on this base line then locate the gap valley in the horizontal integral projection of each strip window. From the positions of these gap valleys, we obtain a series of horizontal separation line segments, as shown in Figure 2(b), and a final upper-lower jaw separation curve as shown in Figure 2(c), by connecting these line segments using spline function [10]. Notice that the third tooth in the upper jaw is well separated from the third tooth in the lower jaw.

3.3. Vertical Separation

Similar to finding the horizontal separation line, we obtain the vertical integral projection of the image using

$$V(x) = \sum_{y=1}^{m} I(x, y)$$

where $m$ is the intersection of column $x$ and the upper-lower jaw separation line. But unlike finding only one gap valley in the horizontal integral projection, we need to find all gap valleys in $V(x)$ because the image contains more than one tooth normally.

Notice that for images in which some teeth appear quite skew, the teeth separation locations of these teeth may not appear as correct gap valleys. To prevent missing any correct gap valleys, we rotate the image with an angle $\theta$ in a range of $[-10^\circ, 10^\circ]$ at an interval of $0.5^\circ$ each, and select the $\theta$-rotated image that produces the most valleys in its $V(x)$ as the desired rotated image for further processing.

Observing $V(x)$, we find that the correct gap valleys occur on the positions where the slope changes from negative to positive. However, finding all points of slope-sign change may cause severe over-segmentation, because it will also detect
points of small variation. Thus, we apply average filter of size 5 to $V(x)$ by

$$V(x) = \frac{V(x-2)+V(x-1)+V(x)+V(x+1)+V(x+2)}{5}, \quad (8)$$

for smoothing the vertical projection $V(x)$.

After selecting the properly rotated image and obtaining its smoothed vertical projection, the next task is finding correct gap valleys. When the widths and the directions of all teeth are about the same in the image, dividing the vertical projection into numerous fixed-size windows then obtaining the gap valley within each window can usually give a good result, provided the window size is set properly. Since teeth do not always grow in similar enough directions for some people, and bitewing images contain molars and premolars whose sizes are significantly different, fixed-size windowing certainly cannot work well for bitewing dental images. For convenience of presentation, we define the following notations first before presenting our adaptive windowing scheme.

Notations:
- $wsize_0$: the minimum size of each window, default to be 60.
- $wsize_i$: the size of window.
- $\varepsilon_i$: dynamic adjustment for $wsize_i$.

Adaptive windowing scheme

1. Scan the smoothed $V(x)$ of the image from left to right till a slope sign changing from positive to negative is found. Mark this location as the left margin of window$_1$, and set $i$=1.
2. Set the initial size of window$_1$ using

$$wsize_i = \frac{1}{i} \sum_{j=1}^{i} wsize_j \quad (9)$$

3. Determine the average slope $S_i$ of the next five consecutive points at the right of the right margin of window$_i$.
4. Adjust window, based on rule (a) if $S_i > 0$, or rule (b) if $S_i < 0$.
   - Rule (a): continue moving the right margin of window$_i$ to the right till the slope changes from positive to negative.
   - Rule (b): continue moving the right margin of window$_i$ to the left till the slope changes from negative to positive.
5. Compute $\varepsilon_i$ as the distance between the beginning and the end of the right margin of the adjusting window, and update the size of window by $wsize_i = wsize_i + \varepsilon_i$. ($\varepsilon_i > 0$ if window$_i$ is expanded, and $\varepsilon_i < 0$ if window$_i$ is shrunk)
6. Set $wsize_{i+1} = wsize_0$ if $wsize_i < wsize_0$.
7. If slope change is not detected within window$_i$, then stop; otherwise, increment $i$ by one and repeat steps 2-6.

Note that Step 6 is to prevent from adjusting the window size to be too small. Following is an example of setting four dynamic windows on a vertical integral projection $V(x)$ having four gap valleys.

**Example:**

1. Scan $V(x)$ to locate the left margin of window$_1$ and add $wsize_0$ to form the initial window$_1$, as shown in Figure 3(a).
2. Adjust window$_1$ based on rule (a) to obtain the adjusted window$_1$ as shown in Figure 3(b), where $\varepsilon_1 > 0$.
3. Compute $wsize_2 = (wsize_0 + wsize_1)/2$ and obtain the initial window$_2$ as shown in Figure 3(c).
4. Adjust window$_2$ based on rule (a) to obtain the adjusted window$_2$ as shown in Figure 3(d), where $\varepsilon_2 > 0$.
5. Compute $wsize_3 = (wsize_0 + wsize_1 + wsize_2)/3$ and obtain the initial window$_3$ as shown in Figure 3(e).
6. Adjust window$_3$ based on rule (b) to obtain the adjusted window$_3$ as shown in Figure 3(f), where $\varepsilon_3 < 0$.
7. Compute $wsize_4 = (wsize_0 + wsize_1 + wsize_2 + wsize_3)/4$ and obtain the initial window$_4$ as shown in Figure 3(g).
8. Stop when no more slope change can be found.

After determining all necessary windows, we locate the gap valley within each window at the position where the vertical projection value is the lowest and plot a vertical line at the position of each gap valley, as shown in Figure 4(a). Notice
that some portions of poorly skewed teeth in Figure 4(a) are segmented to their neighboring teeth, thus we apply a vertical strip windowing technique similar to the technique used in finding the horizontal separation curve of images to resolve the problem. The procedure is as follows.

**Vertical separation line refinement scheme**

For each vertical separation line starting at the point \((x_i, y_i)\), \(y_i\) is the intersection of the vertical separation line drawn at \(x\)-coordinate \(x_i\) and the horizontal separation curve, do the following:

1. Set up the first strip window (height=40, width=20 each) upward (downward) for the upper (lower) jaw image with \((x_i, y_i)\) as the center point of the bottom edge of the window.
2. Take vertical projection of the strip window and plot a vertical line segment at the position of the gap valley in the window, and denote the gap valley position as \(y_{\text{new}}\).
3. Set up the next strip window (height=40, width=20 each) upward (downward) for the upper (lower) jaw image with \((x_{\text{new}}, y_i+\text{height})\) as the center point of the bottom edge of the next window.
4. Repeat Steps 2 and 3 till the window exceeds the image boundary.
5. Apply the spline function to connect all vertical line segments and obtain the refined vertical separation curve.

Figure 4(b) shows all strip windows set up around the vertical separation lines, and Figure 4(c) shows the refined vertical separation curves. We can notice the improvement of the separation results in Figure 4(c), where each ROI contains a single tooth without any portion belonging to its neighboring teeth, and such darkness becomes significant when a part of interdental papilla is missing, the intensity profile of a correct isolation curve will be different from that of an incorrect isolation curve, as shown in Figures 5(b) and (c). Based on the characteristic of the pixel intensity profile of a correct isolation curve, we devise an isolation-curve verification scheme as follows.

**Verification of isolation curves**

1. For each isolation curve, obtain its pixel intensity profile.
2. If the intensity profile of a given isolation curve starts with a low value and rises up for a short section then falls down to near the starting level, accept this line as valid and keep it; otherwise, regard this line as incorrect and remove it.

3.5. Missing-teeth detection for under-segmentation

The aforementioned isolation method can correctly isolate all teeth within images; however, the method will not detect tooth-missing regions. In other words, the tooth and its adjacent tooth-missing region will be segmented together as one ROI, instead of two ROIs of which one contains a tooth and the other contains a tooth-missing region. Such isolation result will cause teeth numbering problem.

Observing the vertical integral projection of the image, we find that the projection curve of the missing tooth region is rather flat and the values are low, while the curve of teeth region goes up and down like a hill. Thus we devise a missing-teeth detection scheme based on the characteristics of the integral projection curve as follows.

**Missing-teeth detection**

1. Obtain the vertical integral projection \(V(x)\) and its first derivative \(V'(x)\), \(x=1, \ldots, n\) (the width) of the rotated upper (lower) jaw image and calculate the mean value of \(V(x)\), denoted as \(V_{\text{mean}}\).
2. For \(x=1 \text{ to } n\), assign position \(x\), denoted as \(P(x)\), to normal or missing-teeth region, using

\[
P(x) \in \begin{cases} \text{Missing-teeth region, if } & |ab[V(x)-V(x+1)]| < 45 \ \& \ \ V(x) < V_{\text{mean}} \\ \text{Normal region, otherwise} \end{cases}
\]

3. Discard the missing-teeth region if its width is less than half of the width of a normal tooth.
4. Add a vertical line at both ends of each detected missing-teeth region.

Figure 6 shows the isolation result of the image before and after applying missing-teeth detection. Notice that the tooth-missing region has been successfully detected and two isolation lines have been added to each end of the tooth-missing region.

![Figure 6. Isolation results without (a) and with (b) missing-teeth detection.](image)

4. Experimental Results

We use 60 bitewing images for tooth isolation experiments. Among all images of upper jaw, the total number of teeth is 252 and the number of missing teeth is 3; whereas among all images of lower jaw, the total number of teeth is 233 and the number of missing teeth is 4. All images are provided by Taichung General Veteran Hospital, Taiwan.

We test these 60 bitewing images by (i) our proposed isolation method, and (ii) Nomir and Abdel-Mottaleb’s method (abbreviated as N+AM in follows), [6], respectively, and compare the isolation accuracy of both methods, which is defined as:

\[
\text{Isolation accuracy} = \frac{\text{the total number of teeth being correctly isolated}}{\text{the total number of teeth}} \times 100\% \quad (10)
\]

Table 1 lists the total number of teeth being correctly isolated and the accuracy of both methods for upper and lower jaws, respectively. Notice that our method achieves accuracy of 95.63% for the upper jaw images and 98.71% for the lower jaw images, while N+AM method achieves 78.17% and 77.68%, respectively, which is close to 84% and 81% reported by the authors in [6].

5. Conclusions

We presented a very effective and fully automatic tooth isolation method in this paper, which is an important pre-processing step of both computer-aided dental diagnosis system and automatic dental identification system. Our method contains four major steps: upper-lower jaw separation, single tooth isolation, isolation-curve verification for over-segmentation, and missing-teeth detection for under-segmentation. The experimental results demonstrated that our method achieves accuracy rates of 95.63% for the upper jaw images and 98.71% for the lower jaw images from a test database of 60 dental radiographs, respectively, which is higher than that of Nomir and Abdel-Mottaleb’s method.

![Table 1. Comparison of Isolation Accuracy](image)

<table>
<thead>
<tr>
<th></th>
<th>Upper jaw</th>
<th>Lower jaw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ours</td>
<td>N+AM</td>
</tr>
<tr>
<td># of teeth</td>
<td>252</td>
<td>233</td>
</tr>
<tr>
<td>Correctly isolated #</td>
<td>241</td>
<td>197</td>
</tr>
<tr>
<td>Isolation accuracy</td>
<td>95.63%</td>
<td>78.17%</td>
</tr>
</tbody>
</table>

Acknowledgements

The research was partially supported by Providence University and Taichung General Veteran Hospital, Taiwan under grant # TCVGH-PU1008102, and National Science Council, ROC under grant # NSC 100-2221-E-126-013.

References