An Algorithm for Automatically Extracting Dental Arch Curve

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Abstract: Dental cone beam CT (CBCT) scans, due to their low radiation dose, are now widely used in the medical diagnosis of patients' oral cavity. The reconstruction of a panoramic view of the dental arch from the scanned CBCT data facilitates the dentist's observation of the patient's oral condition. The most important technique for reconstructing the dental arch panorama is the extraction of the dental arch curve accurately. The existing method is to rely on the experience of the dentist to manually connect the dental arch curve, or use techniques related to threshold segmentation to extract dental arch curve. These methods rely on the experience of dentists on the one hand. On the other hand, when there are interferences such as implants, metal tubes, braces or missing teeth in the patient's mouth, the threshold calculation will be wrong. Based on this, this article starts with the histogram of CBCT data, and proposes a highly robust and fully automatic dental arch curve extraction method. In the actual experiment, the dental arch curves of 40 different patients were extracted, and all the dental arch curves can be accurately and automatically extracted, thus verifying the effectiveness of the proposed algorithm.

1. Introduction
Computed tomography (CT) is a radiology technique used to obtain three-dimensional (3D) images of body structures. In dental clinics, cone beam CT is commonly used [1-2] because of the lower radiation dose compared to traditional CT or X-ray methods. Cone beam CT is designed to perform dental examinations at low radiation levels, allowing analysis of the dental arch area [3].

Panoramic X-ray [4-7] is a two-dimensional (2D) examination used in dentistry. It visualizes the entire dental arch area and adjacent facial structures by projecting the CBCT data within a certain arch thickness. It provides a useful diagnostic tool that can capture the upper and lower jaw, teeth, tissues and surrounding bones in the image. Panoramic images can help dentists visually judge dental diseases, implant surgery planning, orthopedics, etc., so they play an important role in actual stomatology applications. At present, the general method of generating a panoramic image is to find the dental arch area, extract the dental arch curve, and then generate an isometric curve of the dental arch curve to define the thickness of the dental arch, and finally use light accumulation algorithm or X-ray to generate the panoramic image. Therefore, in this process, the extraction of dental arch curve is particularly important, which can be considered the gold standard for the entire panoramic reconstruction.

Yun, Z et.al introduced a method of automatic extraction of dental arch curve. This method takes into account that the brightness of the enamel in the CBCT sequence is relatively large. First, generate the coronal maximum intensity projection (MIP) image of the original CBCT sequence, and then use normal curve fitting at the peak of the MIP image histogram to determine the threshold for threshold segmentation, thereby completing the segmentation of the dental arch region. However, when the patient has implants, metal tubes, braces and other interferences, the threshold calculation will be biased, so that the dental arch area cannot be segmented correctly, so this method is not universal. The other
automatic extraction methods of dental arch curve proposed based on threshold segmentation, also face the same problem of incorrect threshold calculation when high-brightness foreign body interference exists [2,8,9,11,12]. The author of this article carried out the automatic extraction of dental arch curve according to the method described in the above literatures, and the extraction results are shown in Figures 1, 2. It can be seen that when there is no interference in the patient’s CT image, the generated axial MIP has a clearer dental arch area. However, when there are interferences such as implants, root canals, and high density bones in the CT image, the automatically generated axial MIP does not have obvious arch areas.

Hao, Z et.al [10] proposed a method to generate the principal plane of the dental arch area to extract the dental arch curve. However, this method requires manual selection of the midpoint of the tooth and manual filling of the area after the implementation of the area growth method. Documents 13 and 14 also have the same problem [13-14]. So they are all a semi-automated method.

Figure 1. The extraction effect of Dental arch area without interference

Figure 2. The extraction effect of Dental arch area in the presence of interference

Luo, T et.al [15] avoid Threshold-based segmentation, and proposed a method of extracting dental arch region based on K clustering, and given that on the axial MIP of the CBCT data, the empirical parameter of K is 5. Obviously this method can easily lead to the disconnection of the dental arch area. Sa-Ing, V et.al [16] simply divide the axial MIP projection of CBCT into three parts: background, mandible and dental arch respectively. However, this method is only applicable when the patient's CBCT data does not have interfering substances. Wu, T et.al [17] proposed a method of extracting dental arch curve based on principal curvature. Papakosta, T. K et.al [18] proposed a method of extracting dental arch curve on each axial slice. The final dental arch is determined by assessing the similarity of each candidate arch to a template polynomial. However this process takes about 40s to complete.

Considering all of the above, this paper proposes a robust, efficient, automatic method for extracting dental arch curve. First, select a CBCT sequence without interference from implants, metal tubes, braces, etc. We call such a CBCT sequence a template CBCT sequence. For the template CBCT sequence, the region growth method, gamma transformation, morphological calculation and other algorithms are used to extract the dental arch curve and store the relevant algorithm parameters. For other CBCT sequences to extract dental arch curves, firstly use the histogram specification technology to define the histogram of the other CBCT sequences, make them the same or similar to the histogram of the template CBCT sequence, that is to make the spatial grayscale distribution of other CBCT sequences consistent with that of the template CBCT sequence. Then apply the template arch curve extraction algorithm with adjusted parameters directly to other CBCT sequences. After actual verification of the existing 40 sets of CBCT sequences, the results show that the dental arch curve can be better automatically extracted.
2. Method

2.1 Data collection

The clinical CBCT data of 40 patients were randomly collected by Meiya Medical Clinic. The data set is obtained using an oral and maxillofacial cone-beam computed tomography equipment, specification model: SS-X9010DPro-3D, parameters: 1.8Kv, 10mA. The size of the exported DICOM sequence is 480×480×320, the pixel is 0.26×0.26mm, and the layer spacing is 0.31mm. The CT sequences derived from all patients have been anonymized. The data set includes patients of different ages from 40 to 70 years old. Each patient's bone calcium level, tooth loss, CT scan intensity, and presence or absence of implants, metal tubes, and braces are different.

2.2 Selection of Axial Slice Range

Before extracting the dental arch area, the first step is to select a suitable range of axial slices in the CBCT sequence and use this set to generate the axial maximum intensity projection (MIP). If a large range of axial slices is selected, too much bone tissue will be superimposed on the axial MIP, making the extraction of arch curve more difficult due to the interference, as shown in Figure 3. In Figure 3 the full axial CT sequence was used to generate the axial MIP, from which it can be seen that the arch region could not be extracted directly on this MIP.

If the selected range of axial slices is small, some information of interest will be lost and the extraction of dental arch area will be inaccurate, so a suitable range of axial slices needs to be determined. Since the dental arch curve can be directly generated in the mandible, therefore, the range of slices mainly containing the mandible can be directly selected. After statistical analysis of the collected CBCT data, it is found that the mandible is included in the range of 150 to 230 axial slices. To be on the safe side, this range was extended to make the range 140 to 240. The axial slices in this range are the red rectangles in Figure 4. As can be seen in Figure 4, the selected ranges all contain mainly the patient's mandible, so that CBCT slices within this range can be intercepted and used to generate axial MIP and thus extract dental arch curves. The axial MIP of this range is shown in Figure 5. Observe Figure 5 can see the more obvious dental arch area.

![Figure 3. Axial MIP generated by all CT sequences](image_url)

![Figure 4. Selected axial slices range (red rectangle in the figure)](image_url)
2.3 Segmentation of the dental arch area

As can be seen from the coronal MIP in Figure 4, patients have different bone tissue conditions, some have implants, root canals and other accessory structures, so the various disturbances in the generated axial MIP must be different. Therefore, if we directly use some parametric image segmentation algorithms, such as threshold segmentation method, area growth method, shape filtering method, etc., the segmentation parameters adjusted in these algorithms must not be universal, and thus it is difficult to achieve automatic extraction of dental arch curves.

To address this issue, we first performed a segmentation of the dental arch area on the template CBCT data, from which we determined the parameters that would automatically segment the dental arch area. Immediately after, we store the histogram of that template CBCT data as the template histogram. For other CBCT sequences, the histograms of these CBCT sequences are first prescribed so that they are the same or similar to the template histogram, and thus also have a spatial grayscale distribution similar to that of the template CBCT sequences [19]. Since the spatial grayscale distribution of the CBCT data to be segmented is similar to that of the template CBCT data, the algorithm and corresponding parameters used to segment the template CBCT dental arch region can be directly applied to the other CBCT sequences. So the automatic segmentation of dental arch region is realized. The process of histogram specification is as follows. Equation (1) is the probability of histogram of CBCT sequence to be specified:

\[ s_k = T(t_k) = (L - 1) \sum_{j=0}^{k} p_r(t_j) \]  

(1)

Where \( p_r(t_j) \) is the histogram of axial MIP of CBCT sequence to be specified, \( k=0,1,2,\cdots,L-1 \). \( L \) is the total gray level of axial MIP of CBCT sequence to be specified.

\[ G(z_q) = (L - 1) \sum_{i=0}^{q} p_s(z_i) \]  

(2)

Where \( p_s(z_i) \) is the histogram of axial MIP of template CBCT sequence, \( G(z_q) \) is the probability of histogram of axial MIP of template CBCT sequence, \( q=0,1,2,\cdots,L-1 \). \( L \) is the total gray level of axial MIP of template CBCT sequence.

By making equations (1) and (2) equal, the pixel values of the prescribed histogram can be obtained, as shown in equation (3)

\[ z_q = G^{-1}(s_k) \]  

(3)

2.4 Algorithm flow of dental arch curve extraction

The following illustrates the algorithmic process for the extraction of dental arch curve from template CBCT data. First, the CBCT slices located between 140 and 240 in the axial range were intercepted according to what was described in 2.2, and an axial MIP was generated, as shown in Figure 6.
Figure 6. Axial MIP of template CBCT sequence within the selected axial range

It can be seen that there are some radiating artifacts around the dental arch. In order to weaken the influence of these artifacts and to highlight the arch area, we used a gamma transformation for Figure 6, and the formula used for the gamma transformation is shown in equation (4)

\[ s = cr^\gamma \]  

(4)

In equation (4), \( r \) and \( s \) are the input and output pixels, respectively, and \( c \) is the scaling factor after gamma transformation, usually 1. \( \gamma \) is the fraction of gamma transformation, compressing lower gray levels when \( \gamma > 1 \) and conversely compressing higher gray levels when \( \gamma < 1 \). The effect of the gamma transform with \( \gamma > 1 \) is shown in Figure 7.

Figure 7. The effect after the implementation of gamma transformation

It can be seen that in Figure 7 there are clearly two regions, the dental arch region and the cervical region, so the region growth method was next used to convert this figure into a binary map, and the binary image after region growth is shown in Figure 8.

Figure 8. Binary image after region growing

Then the morphological opening operation was implemented to remove the edge burrs of the binary image in Figure 8, and the blob map was generated using the 8-linked domain algorithm, and the segmented dental arch region was obtained by extracting the region with the highest number of pixels in the blob map.
It can be seen that the extracted dental arch has many holes, which is not conducive to the correct extraction of the arch curve in the next step. Therefore, the holes in the dental arch area were filled using the morphological closure operation, and this operation also allowed the edges of the opening in the arch area to be sutured, and the effect after the morphological closure operation is shown in Figure 10.

At this time, if the skeleton curve is extracted directly by distance transformation method, there will be many burr in the skeleton curve, as shown in Figure 11:

The reason why there are so many burrs is that the edge of the dental arch image in Figure 10 is not smooth. To solve this problem we used a strategy of Gaussian filtering followed by threshold segmentation, and the effect after such processing is shown in Figure 12, where we can see that the edges of the dental arch region are smoother than in Figure 10. At this point, the skeleton in Figure 12 is generated by distance transformation, as shown in Figure 13.
By comparing with Figure 11, its burr is less, for figure 13 using the neighboring point number judgment method for edge burr cleaning, the effect after cleaning is shown in Figure 14.

The coordinate points of the skeleton curve are extracted and interpolated by cubic spline [20]. The interpolated cubic spline curve is the dental arch curve to be extracted. As shown the red spline curve in Figure 15.

The above is the algorithm flow of extracting dental arch curve from template CBCT sequence. For other CBCT sequences, the algorithm flow and corresponding parameters are also applicable. The above algorithm flow is summarized as shown in the figure 16.

3. Experimental validation

We apply the proposed algorithm and corresponding parameters directly to 40 sets of CBCT data sets, and the results show that they can accurately and automatically generate dental arch curves.

In order to show the effectiveness of the proposed algorithm, four groups of CBCT sequences were randomly selected to extract the arch curve. The result is shown in Figure 17, As can be seen from Figure 17, the proposed algorithm can successfully extract dental arch curve no matter whether there is implant in the patient's oral cavity, whether the mouth is open, or lack of teeth and other interference, This verifies the effectiveness of the proposed algorithm.

The proposed algorithm flow can be completed in about 8s using matlab. The time used is only one-fifth of the method proposed by Papakosta, T. K. et al which is also run on matlab.
4. Discussion
Although the proposed algorithm is robust, the proposed method needs to limit the range of axial slices. So this method is highly dependent on the CT equipment used. In addition, this method requires a CBCT data set without any interference, and its histogram is used as a template histogram. Due to these two reasons, the proposed method is not convenient to use. Therefore, in our future work, firstly we need to automatically determine the required axial slices range according to the spatial grayscale distribution of the coronal MIP. Secondly we need to manually design a template histogram.

5. Conclusion
This article first selects the range of slices R that mainly contain the mandible in the CBCT sequence. Then obtained the histogram H1 of the axial MIP of the template CBCT sequence in the R range. Then the histogram of other CBCT sequences is regulated as H1, making the spatial distribution of the gray scale of other CBCT sequences is similar to that of the template CBCT sequence. In this way, the algorithm for extracting the dental arch curve of the template CBCT sequence and the corresponding parameters can be directly applied to other CBCT sequences.

Then this article introduces a whole set of algorithm flow for extracting dental arch curve. The CBCT sequences collected from 40 patients were tested and the results showed that the arch curves could be extracted automatically quickly and accurately. Thus, the effectiveness, robustness and automation of the proposed algorithm for extracting dental arch curves were demonstrated.

Figure 16. Four groups of patients were randomly selected for the extraction of dental arch curves Using The proposed algorithm
Figure 17. Algorithm flow chart for automatic extraction of dental arch curve

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