Slice Extraction and Tilt Correction for Automatic Synthesis of Panoramic X-rays from CT Image

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Abstract:

Panoramic X-ray imaging is a standard diagnostic modality in dentistry, offering a comprehensive view of dental structures. Building AI models for dental diagnostics requires diverse datasets, which are challenging to obtain due to high imaging costs and the need for patient privacy protection. To address this challenge, we propose a method for synthesizing panoramic X-ray images from CT images using an elliptical dental arch and a dynamic rotation center. The method also introduces slice extraction and tilt correction relative to the axial reference plane, which have not been considered in previous approaches. Experiments using CT images from 321 individuals showed that the proposed method achieved a mean Structural Similarity Index (SSIM) of 0.644, outperforming conventional techniques. These results suggest that our method can generate panoramic X-rays similar to actual images and support data augmentation in machine learning.

Keywords:

Panoramic X-ray; Computed Tomography; Dental arch; Maximum Intensity Projection

1. Introduction

Panoramic X-ray imaging has been widely adopted as a two-dimensional diagnostic modality in dentistry [1]. By rotating the X-ray tube around the patient's head, it captures a comprehensive view of the dental structures in a single image. In contrast, computed tomography (CT) provides three-dimensional anatomical information and plays a critical role in advanced surgical planning. The volumetric and complex nature of CT images can make it more difficult to interpret than panoramic X-rays, especially in routine clinical settings. Reconstructing panoramic X-rays from CT images facilitates easier interpretation and helps avoid additional imaging, offering a simple and efficient diagnostic aid.

In addition to diagnostic applications, synthetic panoramic X-rays can serve as an effective data augmentation in deep learning. Recent advances in deep learning have significantly improved the performance of computer-aided analysis of X-ray images. However, building robust models requires access to large and diverse datasets, and the acquisition of medical imaging data is often constrained by high costs and privacy concerns [2]. Furthermore, in typical clinical practice, only a single panoramic X-ray is taken per patient, which makes it particularly challenging to collect sufficient data for atypical cases. Synthetic panoramic X-rays reconstructed from CT image can help overcome this limitation by generating diverse images from an individual patient through adjustments to synthesis parameters and algorithms. This approach has the potential to enhance dataset diversity and improve the generalization ability of deep learning models.

Numerous methods have been explored for the automatic synthesis of panoramic X-rays from CT image [3]. Most existing methods extract the patient-specific dental arch and synthesize panoramic X-rays by projecting image data along the identified curve [4–7]. Parida et al. [8] proposed a method to synthesize panoramic X-rays using projection based on a focal trough defined along a semi-elliptical trajectory and moving rotation centers, along with sagittal tilt correction. This method demonstrates robustness in generating panoramic X-rays, even in the presence of metallic implants or missing teeth. However, its effectiveness in correcting tilts relative to the axial and coronal planes has not been fully validated, and a universally applicable method for handling diverse CT image

FIGURE 1. Head CT image.

remains to be established.

This study aims to automatically synthesize high-quality panoramic X-rays from CT image. In addition, we investigate the potential of these synthesized images for data augmentation in deep learning by validating outputs generated through different synthesis methods. Our method performs automatic synthesis based on projection calculations using an elliptical dental arch and dynamically adjusted rotation centers. We also introduce head tilt correction relative to the axial reference plane—a limitation not addressed in previous methods—along with slice extraction for the region of interest (ROI). These enhancements contribute to generating panoramic X-ray images with consistent visual characteristics across various CT datasets.

2. Preliminaries

2.1. Dataset

This study uses a dataset of 321 head CT scans (Fig. 1) and panoramic X-ray images, provided by the Department of Oral and Maxillofacial Surgery at Kobe University Hospital. The use of this dataset was approved by the Ethics Committee of Kobe University Hospital. Each CT scan has an in-plane resolution of 512 × 512 pixels and consists of 125 to 512 slices. The pixel spacing ranges from 0.301 × 0.301 mm to 0.351 × 0.351 mm, and the slice thickness ranges from 0.250 to 0.625 mm. The panoramic X-ray dataset includes 286 images with a resolution of 1,160 × 2,378 pixels and 35 images with a resolution of 1,420 × 2,920 pixels.

2.2. Preprocessing

The grayscale values in CT image reflect the X-ray attenuation characteristics of tissues and are often linearly scaled values that approximate Hounsfield Units (HU). Because dental enamel exhibits higher HU values than the surrounding tissues, maximum intensity projection (MIP) is used to emphasize the structure of the dental arch. This study utilizes coronal MIP images to determine threshold values for tissue segmentation and to identify the appropriate slice range based on the occlusal position.

The intensity histogram of a coronal MIP image derived from the CT image typically exhibits distinct peaks, with one corresponding to bone and another to soft tissue regions. Assuming that the intensity distributions of each tissue type follow a Gaussian distribution due to inherent density variations, a Gaussian curve is fitted to the histogram. Among the fitted Gaussian curves, the one with the highest intensity value is assumed to represent bone tissue. The mean (μ) and standard deviation (σ) of this curve are then used to determine the intensity thresholds for separating the tooth (C_{tooth}) and bone (C_{bone}) regions as follows:

$$C_{\text{tooth}} = \mu + 2.98\sigma \tag{1}$$

$$C_{\text{bone}} = \mu - 2.98\sigma \tag{2}$$

The computed thresholds are subsequently used for tissue segmentation in the preprocessing stage.

A head CT image includes a variety of anatomical structures that are not related to the dental arch. Therefore, axial MIP images generated using all slices may fail to adequately highlight the dental arch, even after thresholding, due to interference from unrelated tissues. To synthesize images corresponding to the field of view typically covered by panoramic X-rays, which spans from the eye level to the lower jaw, the slice range is estimated based on the occlusal position. First, a coronal MIP image is binarized using the threshold for tooth tissue C_{tooth}, defined in Equation (1), to obtain a mask of the tooth region. A horizontal histogram is then constructed by counting the number of mask pixels at each vertical position (y-axis). The occlusal position is determined as the location of the highest peak in the Gaussian curve fitted to the histogram. Based on the mean (E) and standard deviation (w) of the peak, the slice range for the region of interest (ROI) for dental arch extraction, including both the upper and lower jaws, is calculated as follows:

$$I_s = E - 1.8w, \quad I_e = E + 3.8w \tag{3}$$

Similarly, the slice range used for the synthesis of panoramic X-ray images is calculated as follows:

$$S_s = E - 7.4w, \quad S_e = E + 7.4w \tag{4}$$

Slices are extracted according to the calculated ranges for use in dental arch extraction and panoramic image synthesis.

3. Proposed Method

An overview of the proposed method is provided in Fig 2. This study proposes a method to automatically synthesize panoramic X-ray images from diverse CT datasets. Emphasizing head tilt correction relative to the axial reference plane and slice extraction for consistent visual characteristics, the proposed method comprises three main processing steps: jaw region extraction, tilt correction, and panoramic X-ray synthesis. The detailed implementation of each processing step is presented in the subsequent sections.

3.1. Jaw Region Detection

We generate the axial MIP image from the ROI slice range defined in Equation (3), and then binarize it using the threshold for bone tissue C_{bone} defined in Equation (2). Applying the chain code method to the binarized image yields the contour point set of each connected component. We compute the area of each component from its contour and select the one with the largest area as the dental arch mask. To reduce boundary noise, we apply Gaussian smoothing to the contour points of the selected mask. Finally, we compute the bounding rectangle of the dental arch mask to detect the jaw region and determine the projection parameters based on its position and size.

3.2. Tilt Angle Correction

To address variations in head posture during CT scanning, this study performs tilt correction relative to the sagittal and axial reference planes. The following paragraphs describe the correction procedures for each reference plane.

To correct the tilt angle relative to the sagittal plane, we use the axial mask image generated during jaw region detection to estimate the orientation of the jaw. From this orientation, we calculate the tilt angle relative to the sagittal reference plane. The CT volume is then rotated around the superior-inferior axis in the opposite direction of the measured angle to perform the correction.

To correct the tilt angle, we generate a dental region mask by thresholding the sagittal MIP image with the tooth CT value C_{tooth} defined in Equation (1). We apply linear regression to the mask pixels and fit a straight line to approximate the tilt of the dental region. This angle represents the tilt of the dental arch relative to the axial reference plane. Based on this measured angle, we apply rotation correction, where clockwise tilt is defined as positive. To prevent overcorrection, we empirically determined the following correction rules from visual evaluations of sagittal MIP images and their corresponding synthetic outputs:

- For tilt angles greater than $10°$, a $-10°$ rotation is applied.
- For tilt angles between $0°$ and $10°$, a reverse rotation equal to the tilt angle is applied.
- For tilt angles between $-20°$ and $0°$, no rotation correction is applied.
- For tilt angles less than $-20°$, a $5°$ rotation is applied.

These conditions were set based on visual evaluations of the sagittal MIP images and the synthetic panoramic images to avoid excessive rotation.

3.3. Pseudo X-Ray Image Synthesis

Projection calculations are applied to the CT slices within the range defined by Equation (4). For each slice, the projection direction is determined by dynamically calculating the rotation center based on the bounding rectangle of the jaw region. The dental arch is approximated by the elliptical trajectory model defined in Equation (5).

$$x = a_{\mathrm{ell}} \cos t + h, \quad y = b_{\mathrm{ell}} \sin t + k, \quad \left(-\frac{\pi}{9} \leq t \leq \frac{10\pi}{9}\right) \tag{5}$$

The rotation center follows a semi-astroid trajectory model defined in Equation (6).

$$x = a_{\mathrm{ast}} \cos^3 t + h, \quad y = b_{\mathrm{ast}} \sin^3 t + k, \quad (0 \leq t \leq \pi) \tag{6}$$

where, a_{ell} and b_{ell} represent the semi-major and semi-minor axes of the ellipse, while a_{ast} and b_{ast} control the size of the astroid trajectory. The parameters (h, k) specify the center coordinates of both trajectories, and the angle variable t defines the angular extent of the dental arch and the rotation center path.

The dental arch is sampled at equal angular intervals centered on the ellipse. Each sampling point determines the projection direction by targeting its corresponding location on the rotation center trajectory.

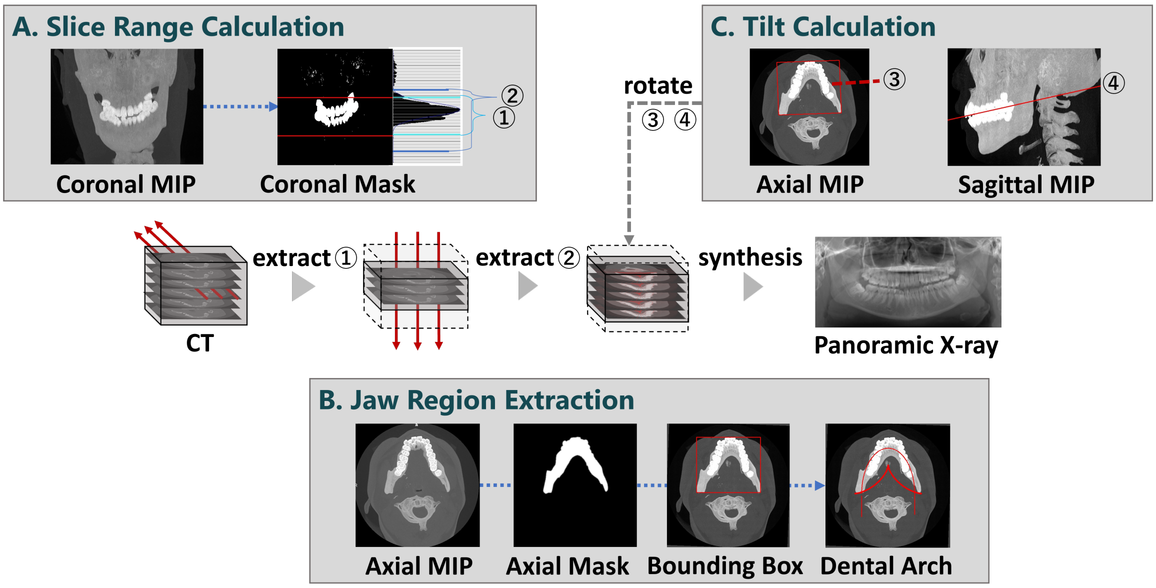

FIGURE 2. Overview of the proposed method for panoramic X-ray synthesis.

4. Experiments

4.1. Experimental Method

The proposed panoramic X-ray synthesis method was applied to CT image from 321 individuals. To evaluate the effects of slice extraction and tilt correction relative to the axial reference plane, we tested four synthesis pipelines with different combinations of these two processes. The quality of the synthesized panoramic X-ray images was assessed through visual comparison with actual panoramic X-rays and by computing the Structural Similarity Index Measure (SSIM).

4.2. Experimental Results

Panoramic X-ray images were synthesized from the CT image of 321 individuals after detecting their jaw regions. Examples of the synthesized panoramic X-ray images from five individuals are presented in Fig 3. The average SSIM values, computed over 321 individuals for each method, are listed in Table 1. The red lines in the coronal MIP image in Fig 3 indicate the slice range used for image synthesis.

As shown in Table 1, applying slice extraction based on the region of interest improved the average SSIM, calculated from synthesized images of 321 individuals. In contrast, tilt correction with respect to the horizontal reference plane did not result in a significant change in SSIM. Tilt correction was applied to the CT images of 65 individuals who satisfied the predefined criteria. For these 65 individuals, the average SSIM of the synthesized images was 0.642, compared to 0.643 for the images generated without correction.

TABLE 1. Average SSIM values for each method

Slices Extraction	Tilt Correction	SSIM
-	-	0.635
-	+	0.635
+	-	0.644
+	+	0.644

In addition to the quantitative evaluation using SSIM, visual assessments were conducted to examine the effects of slice extraction and tilt correction. Figure 4 shows examples of synthesized images with and without slice extraction for CT scans with a wide capture range. Compared to synthesis using all slices, applying slice extraction based on the region of interest excluded slices around the eyes and neck, resulting in images more closely resembling the actual capture range of panoramic X-rays. Figure 5 presents an example of tilt correction applied to a CT scan captured in an upward-facing position. The red line

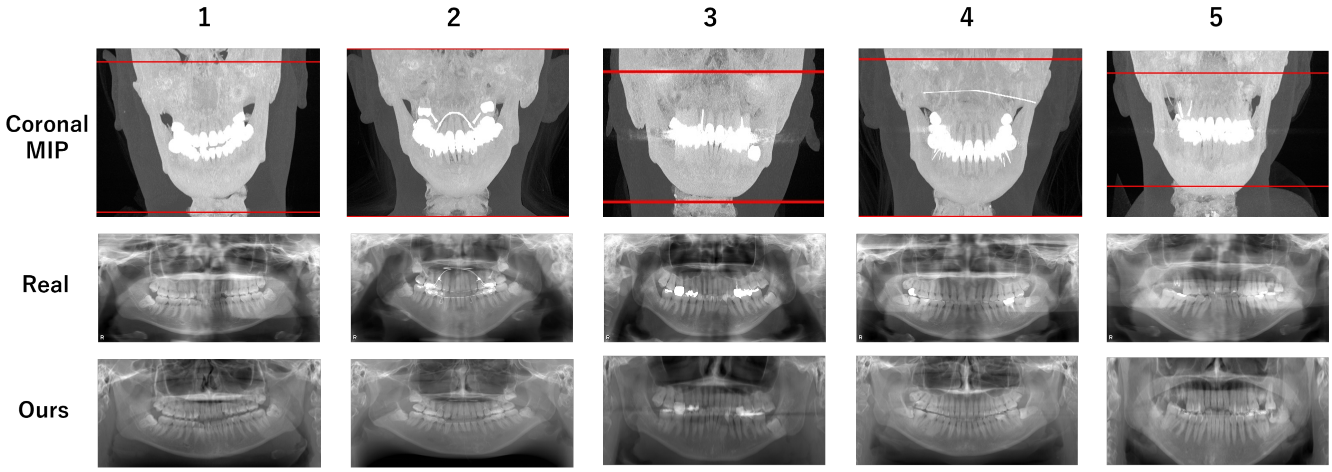

FIGURE 3. Visual comparison of synthesized panoramic X-ray images and original X-ray images.

in the sagittal MIP image represents a linear approximation of the dental region. While SSIM values remained nearly unchanged, the correction visually reduced distortion in the anterior teeth, yielding a more natural dental arch appearance.

While slice extraction improved SSIM values and produced images closer to actual panoramic X-rays, its effectiveness was limited for CT scans with very few slices or irregular intervals. Tilt correction reduced distortion in some cases, especially in upward-facing CT scans, but showed limited contribution to SSIM improvement due to variability in dental arch shapes and artifacts affecting detection accuracy. Overall, both slice extraction and tilt correction have inherent limitations depending on the characteristics of the CT image. Moreover, differences in resolution between CT and panoramic X-rays, as well as the presence of metallic artifacts, impose fundamental limitations on SSIM-based evaluation.

5. Conclusions

This study proposed a method for synthesizing panoramic X-ray images from CT image by applying slice extraction and tilt correction based on dental arch detection. To improve the accuracy of synthetic images, tilt correction was applied with respect to both the horizontal and coronal reference planes. The proposed tilt estimation method, which uses linear approximation of the sagittal mask image, occasionally failed to produce accurate correction angles due to the influence of the third molar or artifacts. To address this, further improvements are needed, such as refining the approximation algorithm or excluding unstable anatomical features to reduce their impact.

Although SSIM-based evaluation showed that tilt correction had a limited effect on similarity scores, visual inspection confirmed its effectiveness in reducing distortion in specific regions such as the anterior teeth. This suggests the potential value of combining quantitative and qualitative criteria when evaluating synthetic image quality.

By adjusting parameters and combining previously proposed methods, the presented pipeline can generate a variety of panoramic X-ray images that reflect real-world variation in CT imaging. In future work, we plan to evaluate the effectiveness of the proposed synthetic dataset for data augmentation in deep learning models for panoramic X-ray analysis, and explore its application in clinical training and diagnostic support systems.

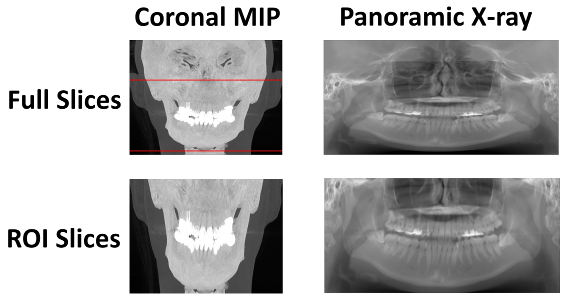

FIGURE 4. Result of slice extraction applied to a CT scan with a wide field of view.

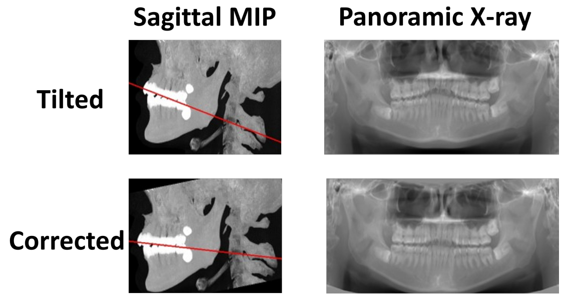

FIGURE 5. Result of tilt correction relative to the axial plane for an upward-facing CT scan.

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