Robust Dental Arch Curve Optimization Using a Standard Arch Form for Panoramic Reconstruction

Songze Zhang[1, 2], Benxiang Jiang[1, 2], Jingyi Lyu[1, 2], and Hongjian Shi[1, 2, *]

1. Guangdong Provincial Key Laboratory of Interdisciplinary Research and Application for Data Science, Beijing Normal-Hong Kong Baptist University, Zhuhai, 519087, China; 2. Hong Kong Baptist University, Hong Kong, 999077, China. **Corresponding Email**: shihj@uic.edu.cn

Introduction

- Panoramic radiography and CBCT are widely used in dental clinical practice, including diagnosis and treatment planning.
- Panoramic reconstruction from CBCT can extract of 3D information in 2D images and reduce patient radiation exposure.
- Existing methods always ignore the geometric convexity of the dental arch and fail to incorporate prior anatomical knowledge of maxillofacial structures. Moreover, they are rarely validated on clinically complex cases such as orthodontic appliances, rigid internal fixation, mixed dentition, complete edentulism, or impacted teeth.
- **Contributions**:
  1. Proposed dental arch curve optimization method integrates prior knowledge of typical maxillofacial anatomy by a statistical standard arch form [1].
  2. Proposed assessment function guides the optimization process and ensure the anatomically accurate and geometrically convex of detected dental arch curve.
  3. Proposed method enables robust and high-quality panoramic image reconstruction across a wide range of challenging CBCT datasets.

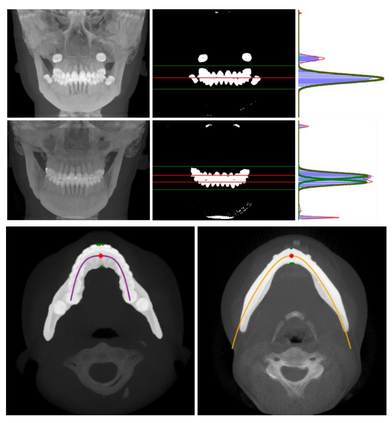
Method

1. Axial MIP Image Generation

Use GMM to fit the histogram of the tooth crown pixels on coronal MIP image by a modified BIC:

$$BIC_{mod} = \alpha \ln N - 2 \ln L$$

Slices in range $\mu \pm 3\sigma$ of one peak component or two peak components are used to generate tooth crown MIP image and the below slices are used to generate mandible MIP image.



2. Standard Dental Arch Curve Fitting

Standard dentition and mandible curves [1] are shifted to fit the jawbone masks of crown and mandible MIP images and overlaid as the **purple** and **orange** curves. These two curves are fused to the **initial standard dental arch curve (blue)** using a window function:

$$W(x) = \left[\frac{x-a}{b-a}\right]^4, x \in [a, b], a < b.$$

3. Dental Arch Curve Optimization

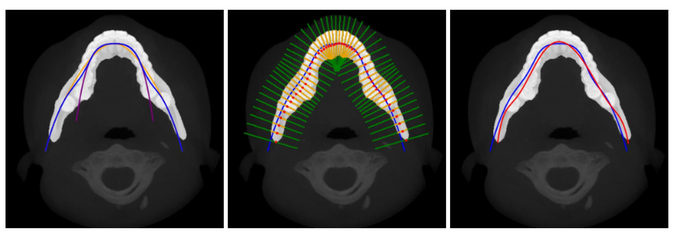
The **central points** of the jawbones in crown MIP are extracted from the **intersection segments** of jawbones and the **perpendicular lines**. The **dental arch curve** is fitted using polynomial regression which follows criteria:

I. Minimize average distance between fitted curve and central points.
II. Use lowest polynomial degree satisfying criterion I to reduce overfitting.
III. Ensure fitted curve is as convex as possible for anatomical plausibility.

To integrate these criteria, we define an assessment function:

$$\mathcal{L}(f_D) = \sum_{i=1}^{n} \left(y_i - f_D(x_i)\right)^2 + \alpha D + \beta(1 - r_{convex}),$$

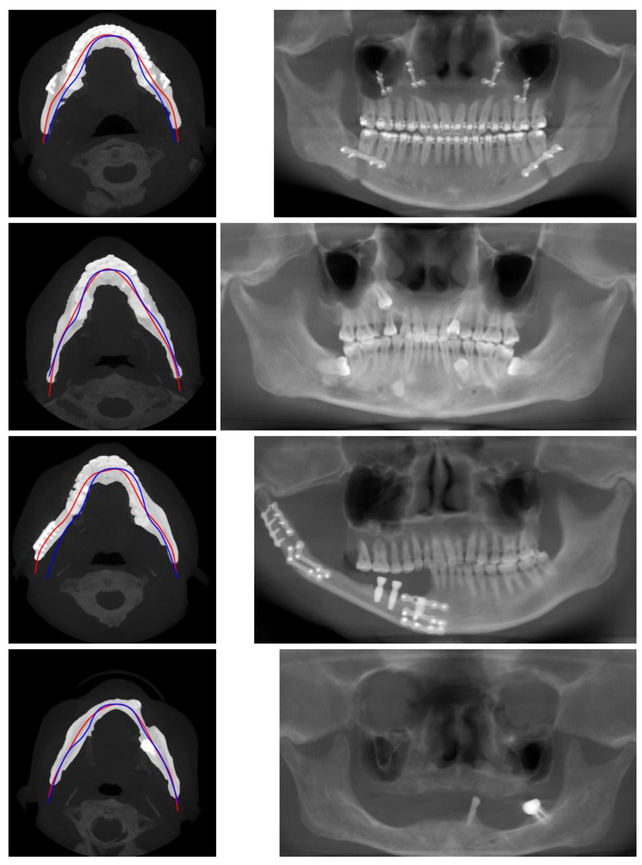
where $f_D(x) = \sum_{j=0}^{D} a_j x^j$ is D degree polynomial, $D \in [2, 20]$, r_{convex} is the proportion of the curve domain with $f_D''(x) > 0$, $\alpha = 1.5$, $\beta = 100$.



Results

This study used 95 public CBCT volumes [2], which include a wide range of clinically challenging cases, orthodontic appliances (7 cases), mixed dentition (1 case), rigid internal fixation (9 cases), root canal (40 cases), crown restoration (49 cases), implants (36 cases), partial edentulism (74 cases), complete edentulism (2 cases) and impacted teeth (13 cases).

Right figures showcase four representative cases. The 1st col shows jawbone-masked axial MIP images, where the **blue** and **red** curves are the **initial standard** and **optimized dental arch curves**. The 2nd col shows the ray-sum panoramic images. Clinical challenges of each cases: 1. Orthodontic appliances and rigid internal fixation; 2. Mixed dentition with impacted teeth; 3. Rigid internal fixation, dental implants, and partial edentulism; 4. Complete edentulism, root canal treatment and crown restorations.



Proposed method performs well to challenging clinical cases and demonstrates **robustness** and **adaptability**.

Degree	6	8	9	12	14	Total
Number	26	58	2	6	3	95
Rate	27.37%	61.05%	2.10%	6.32%	3.16%	100%

Approximately 90% of the fitted dental arch curves were modeled using 6th- or 8th-degree polynomials, as illustrated in the above table. Additionally, most selected degrees were even, which may be attributed to their geometric suitability for producing convex-shaped curves.

Conclusion

- Proposed method integrates statistical dental arch prior knowledge and convexity-constrained optimization.
- Proposed method enables high-quality panoramic image reconstruction with robustness for clinically complex CBCT datasets.

References

1. Welander, U., Nummikoski, P., Tronje, G., McDavid, W.D., Legrell, P.E., Langlais, R.P.: Standard forms of dentition and mandible for applications in rotational panoramic radiography. Dentomaxillofacial Radiology 18, 60–67 (1989)
2. Cui, Z., Fang, Y., Mei, L., Zhang, B., Yu, B., Liu, J., Jiang, C., Sun, Y., Ma, L., Huang, J., Liu, Y., Zhao, Y., Lian, C., Ding, Z., Zhu, M., Shen, D.: A fully automatic AI system for tooth and alveolar bone segmentation from cone-beam CT images. Nature Communications 13, 2096 (2022)