Location Matters: Harnessing Spatial Information to Enhance the Segmentation of the Inferior Alveolar Canal in CBCTs

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Introduction – Segmentation of the Inferior Alveolar Canal (IAC)

A primary **challenge** in segmenting the IAC is the processing of **large 3D volumes**. To mitigate memory constraints, existing approaches employ **patch-based learning**, which involves **subsampling** small three-dimensional patches from the larger volume before inputting them into a deep learning model. However, this method **compromises neural network performance** by reducing access to global contextual information. To address this limitation, **we propose an innovative approach that leverages the spatial information** of the extracted patches by integrating them into a **Transformer architecture.**

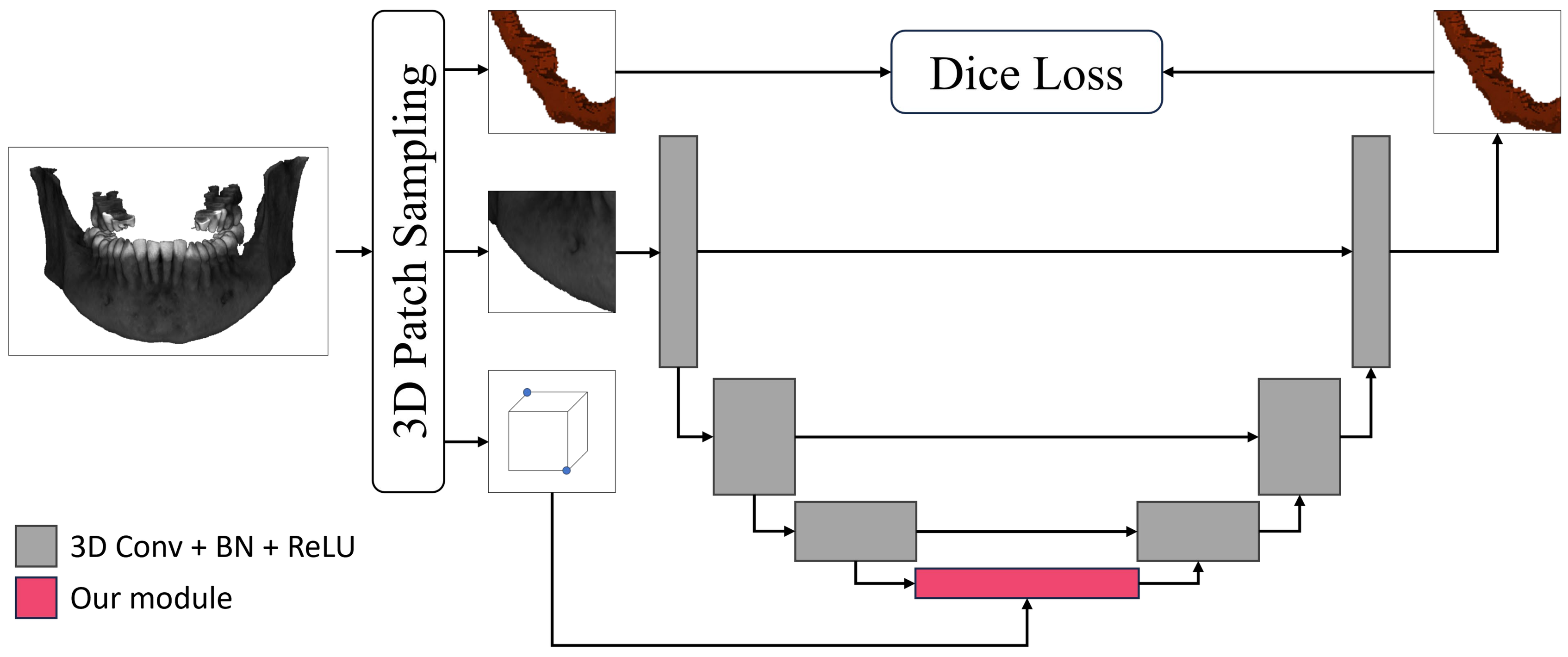


Figure 1. Segmentation pipeline Overview.

Method – Our Proposed Module and Post-processing

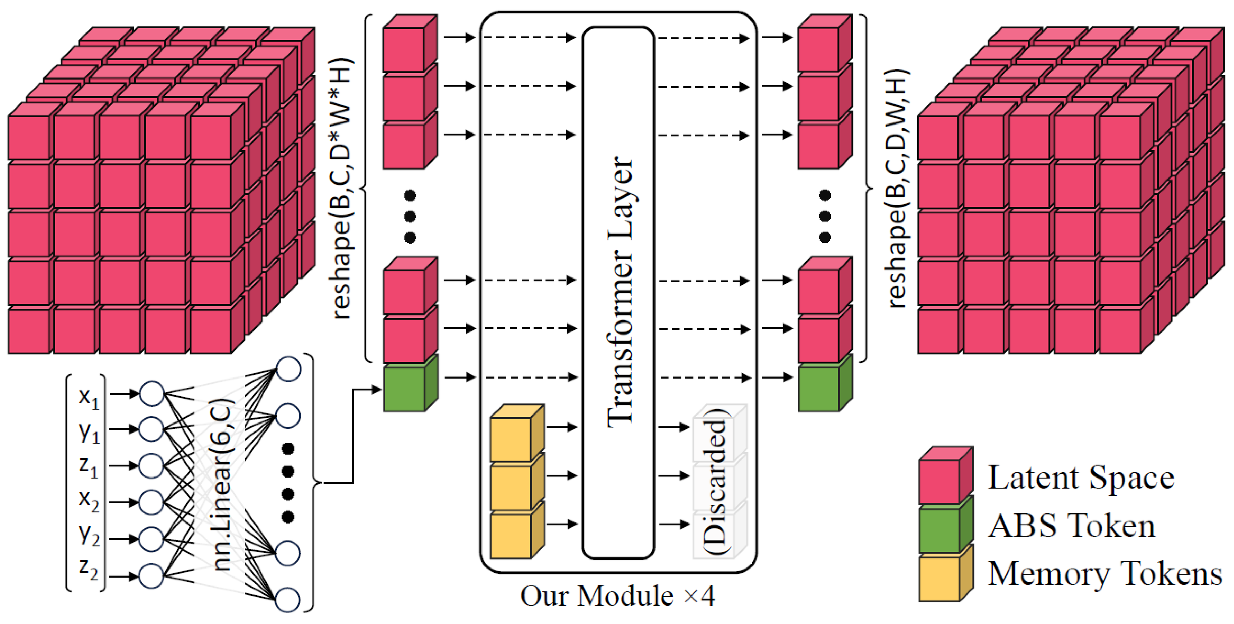


Figure 2. Our Proposed module.

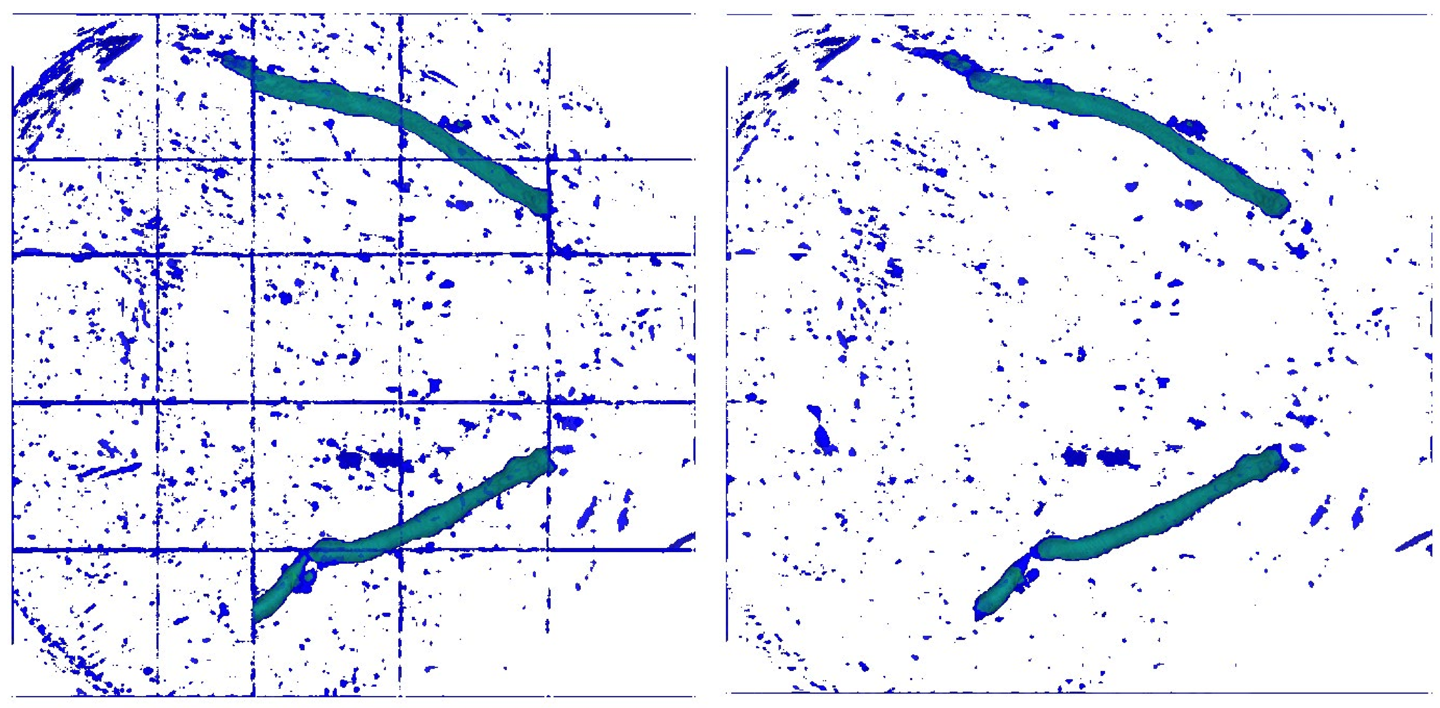
To address the lack of global contextual information inherent in patch-based learning, **we propose a Transformer-based module** (Fig. 2) that leverages two key components:

- **ABS Token**: embeds the absolute position of each extracted patch, providing the Transformer with information about its location;
- **Memory Tokens**: assist the Transformer in retaining crucial prior concepts that are challenging to extract directly from image features but are essential for accurate interpretation.

To enhance overall segmentation performance, we employ a specialized **post-processing** technique inspired by audio encoding literature, specifically the **Hann window function**, which is defined as follows:

$$W_{\text{Hann}}(i) = \frac{1}{2}\left(1 - \cos\frac{2\pi i}{I}\right)$$

where i represents an element within the interval I. To mitigate artifacts, we aggregate the contributions of Hann window functions shifted by $I/2$ (50% overlap). A graphical representation of this post-processing is illustrated in Fig. 3.



(a) (b)

Figure 3. Model output without (a) and with (b) Hann window function post-proc.

Results – Quantitative and Qualitative

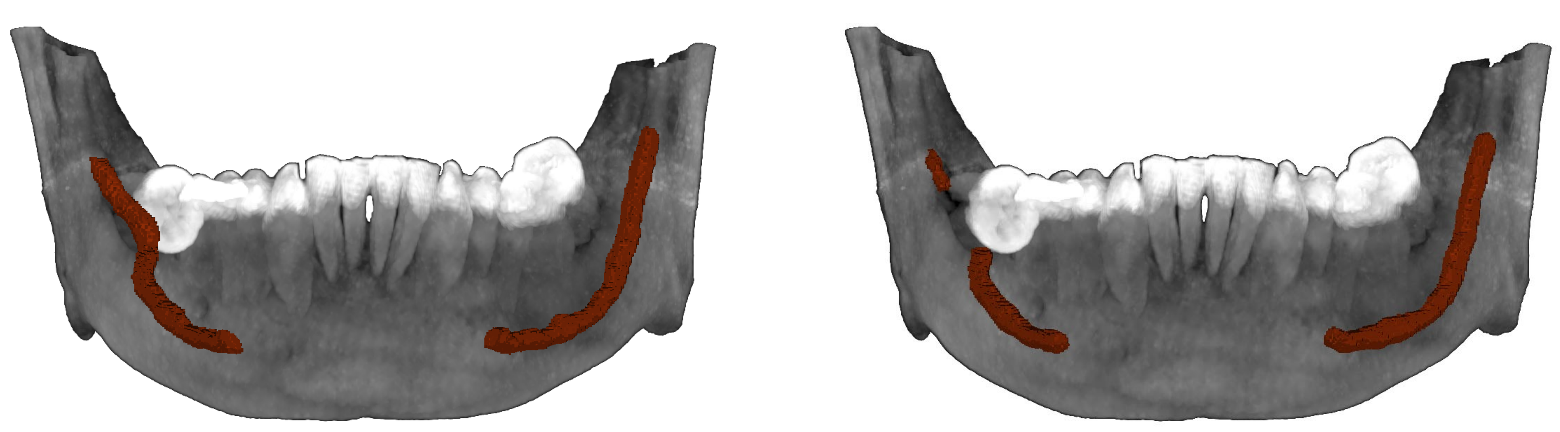
Table 1. Comparison with the state-of-the-art.

Dataset	Method	IoU	Dice
Maxillo	Usman *et al.* [3]	–	0.770
	Cripriano *et al.* [4]	0.650	0.790
	Zhao *et al.* [5]	–	0.810
	Ours	**0.704**	**0.824**
ToothFairy	Ours	**0.710**	**0.831**

Table 2. Ablation Study on the effect of ABS token, memory, and Hann window.

Method	Transf.	ABS Token	Memory	Hann Window	Dice
PosPadUNet3D	✗	✗	0	✗	0.797 ± 0.006
TransPosPadUNet3D	✓	✗	0	✗	0.796 ± 0.009
TransPosPadUNet3D	✓	✓	0	✗	0.801 ± 0.005
TransPosPadUNet3D	✓	✗	128	✗	0.800 ± 0.011
TransPosPadUNet3D	✓	✓	128	✗	0.802 ± 0.004
Ours (Complete)	✓	✓	128	✓	$\mathbf{0.809 \pm 0.004}$

We evaluate our proposal on two datasets, **Maxillo** [1] and **ToothFairy** [2], which are the biggest publicly available datasets for the segmentation of the IAC. The **comparison with the state-of-the-art** is shown in Tab. 1. Meanwhile, the **ablation study** concerning the effect of the ABS token, memory, and Hann window function are presented in Tab. 2. Qualitative results are shown in Fig. 3.



(a) (b)

Figure 3. Qualitative Results: (a) our prediction (b) ground truth.

References

[1] Cipriano et al., Deep Segmentation of the Mandibular Canal: a New 3D Annotated Dataset of CBCT Volumes. IEEE Access, 2022
[2] Bolelli et al., ToothFairy Dataset, https://toothfairy.grand-challenge.org/, MICCAI 2023
[3] Usman et al., Dual-Stage Deeply Supervised Attention-Based Convolutional Neural Networks for Mandibular Canal Segmentation in CBCT Scans, Sensors, 2022
[4] Cipriano et al., Improving Segmentation of the Inferior Alveolar Nerve through Deep Label Propagation, CVPR 2022
[5] Zhao et al., Whole mandibular canal segmentation using transformed dental CBCT volume in Frenet frame, Heliyon 2023