Advances in Tooth Detection and Segmentation in Dental Panoramic X-ray Images: A Review

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치아 파노라마 X선 영상에서 치아 검출 및 치아 영상 분할방법: 리뷰

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Abstract

Dental panoramic X-ray imaging has become an indispensable tool for modern dentistry, providing valuable information on the condition and alignment of teeth. As a result, various deep learning-based techniques have been developed in recent years to detect, segment accurately, and number teeth from panoramic images. This review paper discusses four recent studies that have proposed innovative deep learning-based methods for tooth detection, segmentation, and numbering. The models presented in these studies utilize convolutional neural networks (CNNs), U-Nets, and transformer-based architectures to achieve state-of-the-art results. In addition, we highlight the experimental results and future directions for further research in this field.

Ⅰ. Introduction

Dental panoramic X-ray imaging is crucial for diagnosing and treating dental diseases and abnormalities. These images provide a comprehensive view of the teeth, jaws, and surrounding structures, aiding in the detection and diagnosis of various dental conditions, such as caries, periodontal disease, and malocclusion. However, analyzing panoramic images can be time-consuming and prone to error. Therefore, the development of automated tooth detection, segmentation, and numbering techniques has received increasing attention in recent years. This review paper compares the recent deep learning-based methods proposed for these tasks.

The models, such as point-wise localization with distance regularization, teeth U-Net with context semantics and contrast enhancement, deep learning with heuristic algorithms, and transformer-based tooth segmentation, have shown remarkable results in terms of accuracy and performance. These approaches leverage the power of deep learning to capture intricate features and patterns in panoramic X-ray images, enabling the precise identification, segmentation, and numbering of individual teeth.

By automating these tasks, deep learning-based methods can significantly reduce the manual labor and time required for dental analysis, allowing dental professionals to focus more on diagnosis and treatment planning. Moreover, these methods offer the potential for consistent and standardized results, minimizing the risk of human error and variability in tooth analysis.

However, there are still challenges that need to be addressed and avenues for future research. The evaluation of these methods on larger and more diverse datasets will further validate their robustness and generalizability. Additionally, real-time implementation and integration into clinical practice are crucial for their practical application. Furthermore, exploring deep learning techniques with other imaging modalities, such as CBCT, can provide a comprehensive and multimodal approach to dental analysis, enabling more accurate and detailed assessments.

Ⅱ. Methods for Tooth Diagnosis

Four recent studies were selected for this review, each proposing a novel deep learning-based technique for tooth detection, segmentation, and numbering. The first study by Chung *et al.* [1] proposed a point-wise localization and distance regularization method for individual tooth detection and identification from dental panoramic X-ray images. The method utilizes a CNN to learn feature representations and estimate the locations of individual teeth. The second study by Hou *et al.* [2] proposed a teeth U-Net, a segmentation model for dental panoramic X-ray images that incorporates context semantics and contrast enhancement. The model was trained to segment individual teeth and enhance the contrast between the teeth and the surrounding structures. The third study by Karaoglu *et al.* [3] proposed a novel method for numbering teeth in panoramic images based on deep learning and a heuristic algorithm. The method utilizes a CNN to detect teeth and a heuristic algorithm to assign numbers to the detected teeth. Finally, Sheng *et al.* [4] proposed a transformer-based deep-learning network for tooth segmentation on panoramic radiographs.

Table 1: Comparison of the four models with different evaluation metrics:

Models	Approaches	Task	AP	IoU	Precision	Recall	Accuracy	F1 Score
Chung [1]	Point-based Distance Regularization Method (818 Images)	Tooth Detection	0.81	0.84	-	-	-	-
		Tooth Identification	-	-	0.9970	0.9720	-	-
Hou [2]	Teeth U-Net (1500 images)	Tooth Segmentation	-	-	0.9462	0.9451	0.9853	-
Karaoglu [3]	Mask RCNN with Heuristic Algorithm (2702 Images)	Tooth Detection and Numbering	-	-	0.9608	0.9565	-	0.9587
Sheng [4]	Transformer-based Deep Learning (100 images)	Tooth Segmentation	-	0.4689	-	-	0.8852	0.6372

The method utilizes a transformer-based architecture to capture global context information and perform pixel-level segmentation of individual teeth.

Ⅲ. Exprimental Analysis

The experimental results reported by the four studies demonstrate the effectiveness and efficiency of the proposed methods. In [1], the focus is to detect all 32 teeth and identify them, even if the teeth are missing. In [2], the focus is segmentation, but there are 12 categories of dataset images with grade differences. Also, the model works on binary semantic segmentation of panoramic images containing all morphological and structural conditions of the teeth. In [3], the model achieves high accuracy in tooth numbering using a heuristic algorithm for all 32 multi-class teeth. Finally, in [4], the model demonstrates the feasibility of Transformeer-based Unet for tooth segmentation. However, it still has a scope for improvement.

In summary, each model has performed well on various approaches for different tooth-related tasks. However, the comprehensive comparison is limited due to varying metrics.

IV. Future Directions

Despite the significant progress in automated tooth detection, segmentation, and numbering, several challenges still need to be addressed. First, the performance of these methods needs to be evaluated on larger datasets to ensure their generalizability. Second, developing real-time tooth detection and segmentation systems is necessary to facilitate clinical use. Third, integrating these methods with other dental imaging modalities, such as cone-beam computed tomography (CBCT), can further improve the accuracy of dental diagnosis and treatment planning.

V. Conclusion

In conclusion, the recent advancements in deep learning-based methods for tooth detection, segmentation, and numbering from panoramic X-ray images have shown great promise in automating dental analysis. These models offer accurate and efficient solutions, potentially reducing human error and improving the workflow of dental professionals. However, further research and development in this field are necessary to address challenges, validate the methods on larger datasets, and explore integration with other imaging modalities for comprehensive dental diagnosis and treatment planning. Nevertheless, deep learning-based tooth detection, segmentation, and numbering approaches have shown remarkable progress in automating dental panoramic X-ray analysis. Continued research and development in this field will improve dental care by providing efficient and accurate tools for dental professionals.

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