AI POWERED DENTAL SCAN ANALYSIS

Project Reference No.: *49S_BE_1368*

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Keywords:
Orthodontic treatment planning, Tooth segmentation, Landmark localization, 3D intraoral scans, PointNet-Reg

Introduction:

Orthodontics focuses on correcting misaligned teeth and jaws to improve oral health and aesthetics. A key step in treatment planning involves accurate tooth segmentation and identification of anatomical landmarks from 3D intraoral scans. Traditionally, these tasks are performed manually, making them time-consuming, labor-intensive, and dependent on expert skill, which can lead to inconsistencies. Semi-automated methods offer limited support, highlighting the need for a fully automated and reliable solution.

With advancements in AI, particularly deep learning and 3D computer vision, this project proposes a two-stage approach for automated orthodontic analysis. It uses iMeshSegNet for precise tooth segmentation and a modified PointNet (PointNet-Reg) for landmark localization through heatmap regression. This combined system enables accurate tooth alignment simulation, reduces diagnostic time, improves treatment precision, and supports personalized orthodontic planning while contributing to digital healthcare innovation.

The proposed system integrates segmentation and landmark detection into a unified pipeline, enabling efficient end-to-end orthodontic analysis. It is evaluated using metrics such as Dice coefficient and Mean Absolute Error (MAE) to ensure high accuracy and reliability. The framework also includes preprocessing techniques like noise removal and data augmentation to enhance model performance. By minimizing human intervention, the system improves consistency and scalability for large datasets. Additionally, it provides visualization tools to assist orthodontists in better decision-making. Overall, this approach enhances clinical efficiency and supports real-world deployment in digital dentistry.

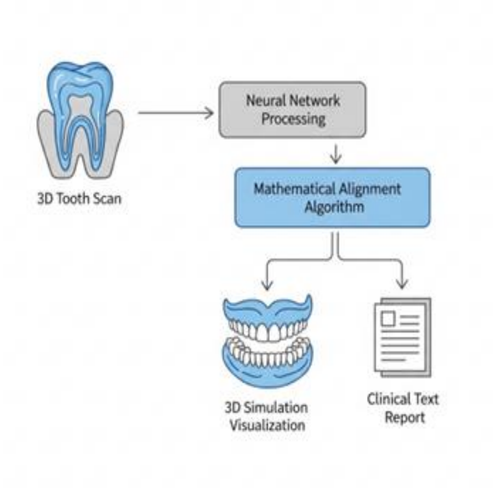

Figure 1: Architecture of Dental AI Pro

Objectives:

1. Develop an AI-based system to automate tooth segmentation and landmark detection from 3D intraoral scans.
    a. This involves designing a framework that can process complex 3D dental data efficiently.
    The system should accurately identify and separate individual teeth from scan data.
    It should also detect clinically important anatomical landmarks required for diagnosis.
    The goal is to reduce dependency on manual analysis by orthodontists.

2. Implement advanced models like iMeshSegNet and PointNet-Reg for accurate dental analysis.
    a. iMeshSegNet will be used for precise segmentation of teeth from 3D mesh data.
    b. It preserves geometric details and improves segmentation quality.
    c. PointNet-Reg will be used for landmark localization on point cloud data.
    d. Heatmap regression techniques will ensure high precision in detecting key points.

3. Integrate segmentation and localization into a unified pipeline for tooth alignment simulation.
    a. The system will combine outputs from both models into a single workflow.
    b. This enables seamless processing from raw scan data to final analysis.
    c. It will support simulation of patient-specific tooth alignment.
    d. The pipeline will ensure efficiency and consistency in results.

4. Improve efficiency, accuracy, and reduce manual effort in orthodontic treatment planning.
    a. The system aims to significantly reduce diagnostic time.

b. It enhances accuracy compared to traditional and semi-automated methods.
c. It minimizes human errors and variability in results.
d. Overall, it supports orthodontists in making faster and better clinical decisions

Methodology:

The proposed methodology follows a two-stage deep learning approach for automated dental analysis. In the first stage, tooth segmentation is performed using a graph neural network model called iMeshSegNet, which operates directly on 3D intraoral mesh data. This approach preserves the geometric structure of teeth and ensures accurate identification of individual teeth. Before segmentation, preprocessing steps such as noise removal, normalization, mesh-to-point cloud conversion, and data augmentation (rotation, scaling, jittering) are applied to improve model robustness and performance.

In the second stage, landmark localization is carried out using a modified PointNet model (PointNet-Reg). This model processes point cloud data to detect clinically important anatomical landmarks through heatmap regression, enabling precise and sub-millimeter localization. The system uses techniques like multi-task learning and optimized loss functions (Dice loss, cross-entropy, MSE/L1 loss) to enhance both segmentation and localization accuracy.

Finally, both stages are integrated into a unified pipeline that enables patient-specific tooth alignment simulation. The model is evaluated using metrics such as Dice coefficient and Mean Absolute Error (MAE), along with qualitative clinical validation. This end-to-end approach ensures high accuracy, reduced processing time, and practical applicability in real-world orthodontic workflows.

Additionally, the system is designed to be scalable and adaptable to different types of dental datasets and imaging modalities.

It can be further enhanced with real-time processing capabilities for faster clinical decision-making.

This methodology also lays the foundation for future integration with fully automated orthodontic treatment planning systems.

Result and Conclusion:

The proposed system is expected to deliver a functional AI-based prototype capable of accurately segmenting teeth, detecting anatomical landmarks, and simulating patient-specific tooth alignment. Using models like iMeshSegNet and PointNet-Reg, the system aims to achieve high segmentation accuracy and precise landmark localization with minimal error. Performance is evaluated using metrics such as Dice coefficient, Mean Absolute Error (MAE), processing time, and clinical reliability, ensuring that the results meet practical orthodontic standards. Additionally, the system provides an interactive interface for visualization, enabling orthodontists to analyze scans and review alignment simulations efficiently.

The results indicate significant improvements over traditional manual and semi-automated methods by reducing diagnostic time, minimizing human effort, and enhancing consistency.

The integration of deep learning techniques allows faster and more reliable analysis, making the system suitable for real-world clinical applications and scalable for large datasets.
In conclusion, this project demonstrates the potential of artificial intelligence to transform orthodontic treatment planning by making it more accurate, efficient, and patient-specific. It contributes to digital healthcare by improving accessibility, reducing costs, and supporting better clinical decision-making. Overall, the system represents a step forward in AI-driven dentistry, enabling smarter and more reliable orthodontic workflows.

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Future Scope:

The future scope of this project includes:

1. The system can be extended by incorporating real-time analysis capabilities and integrating it into existing clinical orthodontic software. This would allow orthodontists to process intraoral scans instantly and receive immediate insights for diagnosis and treatment planning. Such integration would improve workflow efficiency and make the solution more practical for everyday clinical use. Additionally, seamless connectivity with dental imaging systems and electronic health records can further enhance usability. This step is crucial for transitioning the project from a research prototype to a real-world clinical tool.
2. The important direction is improving model performance by training on larger and more diverse datasets. Including data from different populations, imaging devices, and dental conditions can enhance the model's robustness and generalization. Advanced architectures such as transformers and hybrid deep learning models can be explored to capture more complex spatial relationships in 3D data. Continuous optimization and fine-tuning will help achieve higher accuracy and reliability. This will ensure that the system performs consistently across varied clinical scenarios.Enable fully automated treatment planning with AI-driven decision support and personalized orthodontic solutions.
3. Finally, the system can evolve into a fully automated treatment planning solution powered by AI-driven decision support. It can assist orthodontists by recommending optimal treatment strategies based on patient-specific data. Personalized orthodontic solutions can be generated, improving treatment outcomes and patient satisfaction. The integration of predictive analytics can also help in forecasting treatment progress and potential complications. Overall, this advancement will lead to smarter, more efficient, and patient-centered orthodontic care.