Robust harmonic field based tooth segmentation in real-life noisy scanned mesh

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INTRODUCTION

- Dental Mesh Segmentation allows dentists to simulate moving teeth without making several plaster models.
- **Harmonic field based models** [2, 3, 5] improve performance of dental mesh segmentation compared to **curvature based models** [1, 4], but it is still vulnerable to real noisy meshes.
- We propose a noise robust algorithm that can handle artifacts in **real meshes.**

METHODS

- **Harmonic Field based model**

$$A\Phi = b: \quad A = \begin{bmatrix} L \\ C \end{bmatrix}, \quad b = \begin{bmatrix} 0 \\ b' \end{bmatrix}$$

where

L is Laplacian matrix of which weight [3] is

$$w_{ij} = \frac{\gamma_{ij}(cot\alpha_{ij} + cot\beta_{ij})}{2}$$

C is constraint matrix $c_{ij} = \begin{cases} \omega, & \text{for } i = j \text{ and } i \in P, \\ 0, & \text{otherwise,} \end{cases}$

P is set of feature points.

b' is boundary condition vector proposed by [3]

- **Additional Ground (AG)**

Some additional grounds are added to revise harmonic field affected by noise meshes and shapes.

- **Flipping Dirichlet boundary condition (FD)**

Use two Dirichlet boundary conditions giving weights to different groups of input points.

$$b'_{1i} = \begin{cases} \omega, & \text{for } i \in P_{even} \\ 0.5\omega, & \text{for } i \in P_{ground}, \\ 0, & \text{for } i \in P_{odd} \end{cases} \qquad b'_{2i} = \begin{cases} \omega, & \text{for } i \in P_{odd} \\ 0.5\omega, & \text{for } i \in P_{ground} \\ 0, & \text{for } i \in P_{even} \end{cases}$$

- **Convex Segmentation (CS)**

$$Seg = Seg \cup \left(\bigcup_i V_i\right)$$

$$V_i = \{v \mid \text{proj}(v) \in convexHull(\text{proj}(Seg \cap (\bigcup_{j \le i} S_j)))\}$$

S_j is a horizontal slice of each tooth indexed from the bottom.

QUALITATIVE RESULT

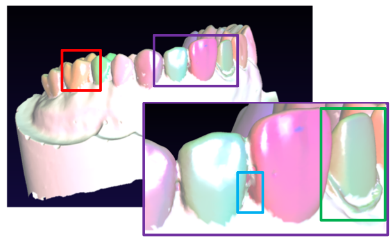

Fig. 1 Qualitative result of our algorithms on mandible with an abraded tooth, a crown and a hole.

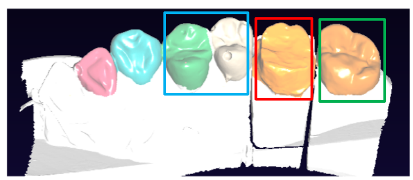

Fig. 2 Qualitative result of our algorithms on mandible with a prepared tooth, an isolated molar and craters.

QUANTITATIVE RESULT

- **Overlap Ratio**

Table 1. Overlap ratio (IoU) on four different meshes

Data	baseline	ours
mandible w/ an abraded tooth	0.0000	0.0005
mandible w/ a prepared tooth	0.0000	0.0000
mandible w/ crowns	0.0000	0.0000
maxillary teeth	0.0000	0.0000

- Baseline model does not make any overlaps
- Our model generates negligible overlap on one meshes due to Convex Segmentation.

- **Comparison with the baseline**

Table 2. Human Evaluation (25 experts) with seven point scale for comparing with the baseline

Data	baseline		ours	
	Avg	Std	Avg	Std
mandible w/ an abraded tooth	3.16	1.40	**5.72**	0.94
mandible w/ a prepared tooth	3.96	1.43	**5.44**	1.29
mandible w/ crowns	3.60	0.91	**5.00**	1.15
maxillary teeth	3.40	1.26	**5.40**	1.12

- Our model outperforms the baseline model with scores higher than 4 (median of seven point scale).
- Results of the baseline model get same or less than 4.

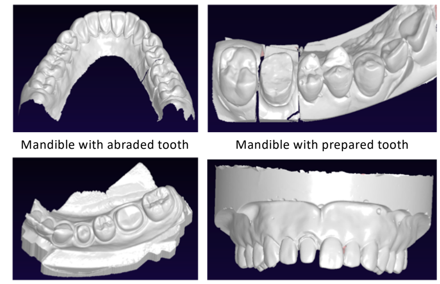

Fig. 2 Mesh data used for quantitative experiments

ABLATION STUDY

Table 2. Human Evaluation (seven point scale)

Model	Avg	Std
baseline	2.88	1.36
baseline + AG	3.84	1.11
baseline + AG + FD	4.68	0.90
baseline + AG + FD + CS	**6.20**	0.65

- Each introduced algorithm effectively improves the quality of dental mesh segmentation.

CONCLUSIONS

- **Proposed algorithms can improve the performance of dental mesh segmentation from the baseline harmonic field based model.**
- **Our model differentiates well on abraded teeth, prepared teeth, and crowns.**
- **However, Flipping Dirichlet boundary condition and Convex Segmentation can cause overlap between two or more teeth.**

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