Machine-Learning Enabled Interactive Virtual Reality Simulator for Preoperative Planning of Endoscopic Sinus and Skull-Based Surgery

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Introduction

- Interactive VR is a valuable teaching tool that is transforming the landscape of medicine
- Current simulators rely on manually generated data
- Endoscopic sinus surgery presents complex anatomy that would benefit from a modality like VR
- We aim to harness our novel, data-efficient subspace approximation with augmented kernels (Saak) transform-based machine learning method to automatically segment sinus CT scans and prepare a VR tool to explore a specific patient's anatomy prior to endoscopic sinus surgery

Methods

- We manually segmented the soft tissue of 548 images derived from 2 sinus CT scans in *Amira*
- Our Saak-based machine learning algorithm (Fig. 1) was trained with randomly selected images
- The trained algorithm was used to perform automatic soft and bony tissue segmentation of CT scans
- We validated the segmentation results using the dice similarity coefficient (DSC) and intersection over union (IOU)
- We exported the segmented scans into our *Unity* VR interface that enables endoscopic exploration

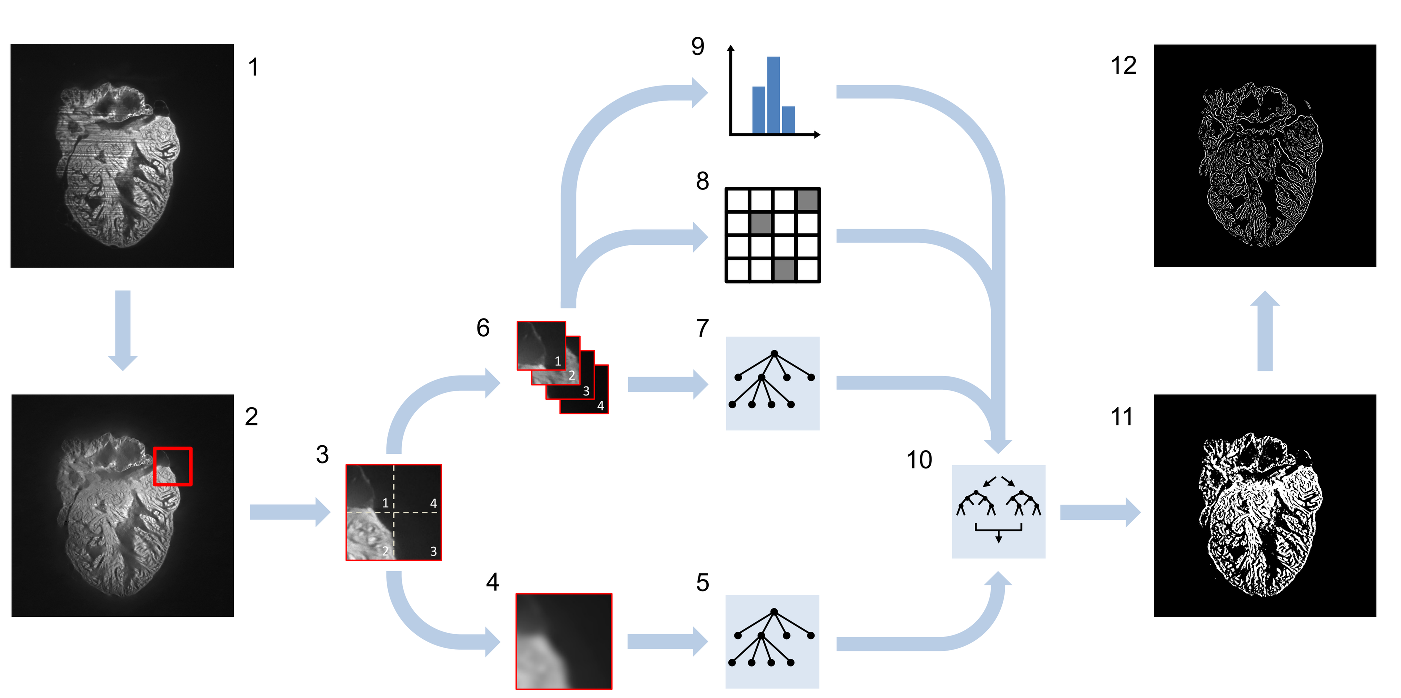

Figure 1. Software Map. (1) Raw image (2) Denoised image post-VSNR (3) Image patch (4) Patch downsampled with averaging filter (5) SAAK transform (6) Subpatches (7) SAAK transform (8) Pixel location (9) Pixel intensity (10) Random forest classifier (11) Segmented result (12) Edge information

Figures and Results

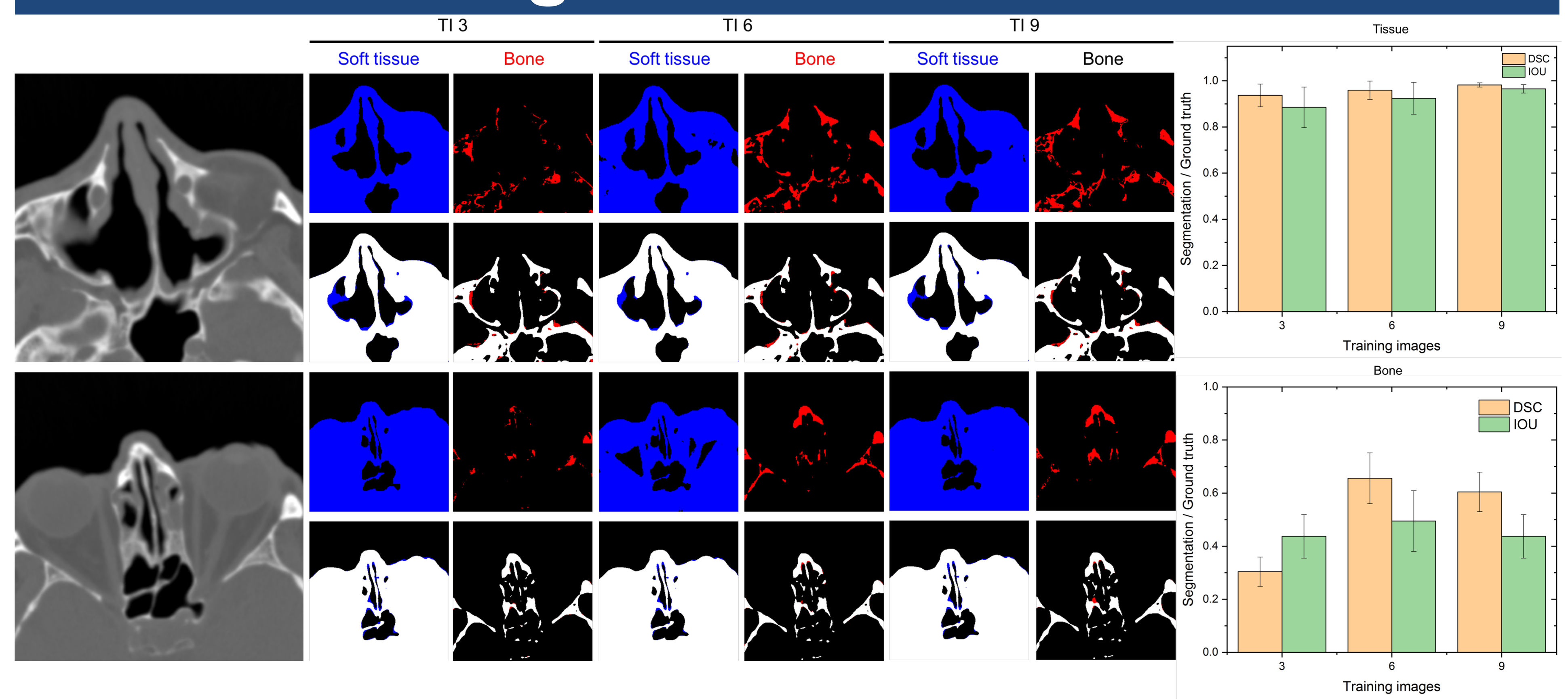

Figure 2. Qualitative and Quantitative Comparison of Segmentation Results. (A-B) The Saak transform-based method's soft tissue (blue) and bone (red) segmentation results overlaid with the ground truth (white) for 2 axial slices of a CT scan. (C-D) The DSC and IOU results of our automatic segmentation method for soft tissue and bone computed using 24 randomly selected validation image sets.

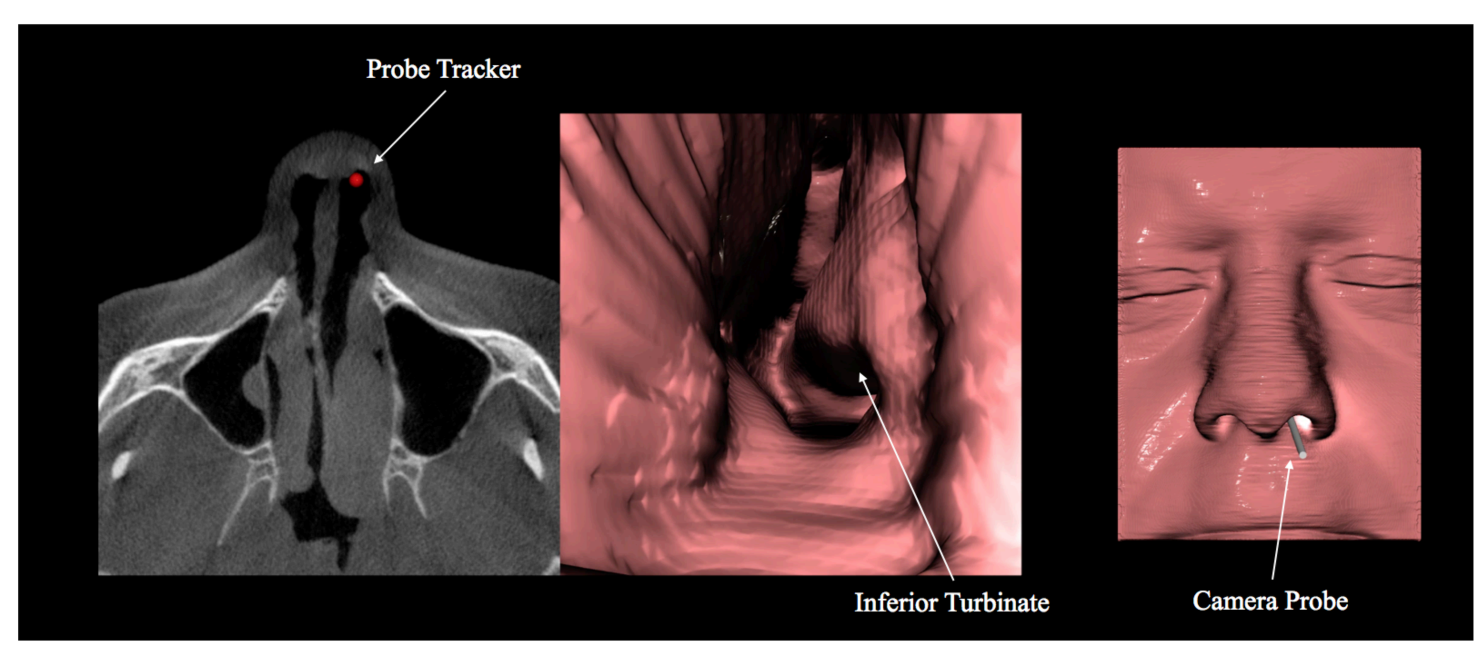

Figure 3. *Unity* VR Interface. A user controllable probe is mapped to a scrolling axial view of the raw CT scan. The central display shows the output of the endoscopic camera, revealing the patient's anatomy.

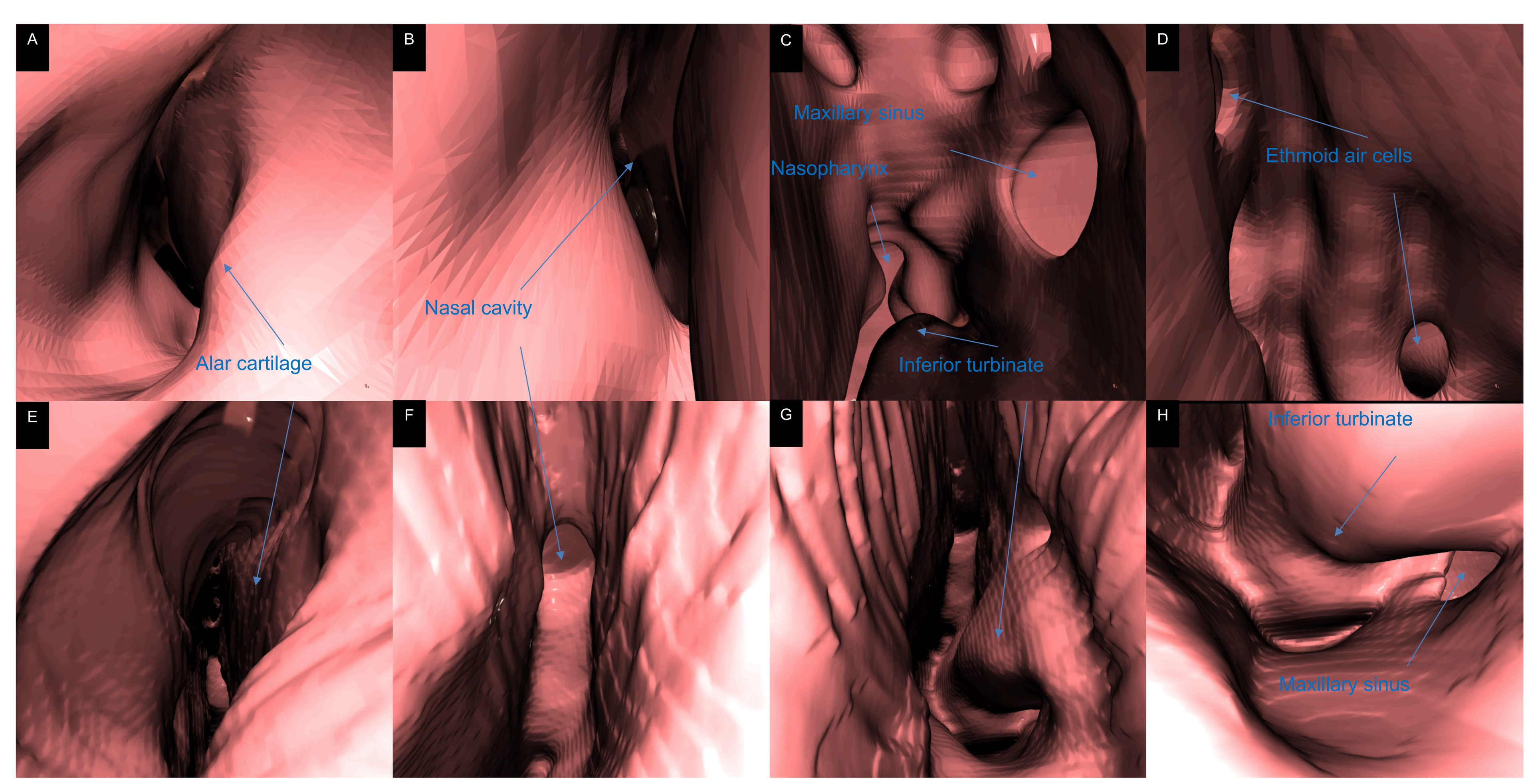

Figure 4. Labeled Anatomical Features. (A-D) Selected views of one patients anatomy. (E-H) Parallel views in second patient highlighting anatomical differences. The first patient has a narrower nasal cavity (B) due to obstruction compared to the second patient (F). While the natural orifice of the maxillary sinus is normally located above the inferior turbinate (C), the second patient has a passageway below the turbinate from previous surgery (H).

Results and Discussion

Segmentation

- Saak transform-based segmentation produced DSC and IOU coefficients of 0.982 ± 0.009 and 0.965 ± 0.018 respectively for soft tissue (Fig. 2).
- Qualitative examination of soft tissue segmentation results reveals minimal noise and clear airspaces (Fig. 2.).

VR Interface

- The automatic segmentation method enabled us to design a VR simulator with controllable endoscopic camera and real-time probe mapping (Fig. 3).
- The simulator allows visualization of patient-specific anatomic structures for operative planning (Fig. 4.).

Conclusions

- By enabling patient-specific demos, automatic segmentation is a key step in making VR an accessible and clinically relevant tool.
- Further studies improving the quality of other structures like bone will improve the user ability to view key anatomy
- Subsequent projects can integrate our segmentation method with advancing VR technology to not just plan a surgery but also practice it beforehand

Acknowledgements

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