Project 12

Evaluation of CT Registration for Image-based Sinus Reconstruction

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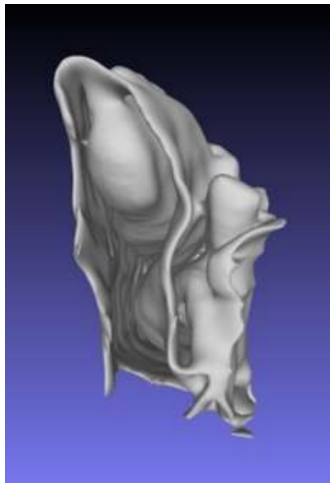
Project Summary

GOAL: Implement a quantitative framework to evaluate registration between image-based 3D reconstruction of the sinus anatomy and their corresponding CT volume

3D Reconstruction



Segmented CT

Paper Details

Title: Reconstructing Sinus Anatomy from Endoscopic Video – Towards a Radiation-Free Approach for Quantitative Longitudinal Assessment

Authors: Xingtong Liu, Maia Stiber, Jindan Huang, Masaru Ishii, Gregory D. Hager, Russell H. Taylor, Mathias Unberath

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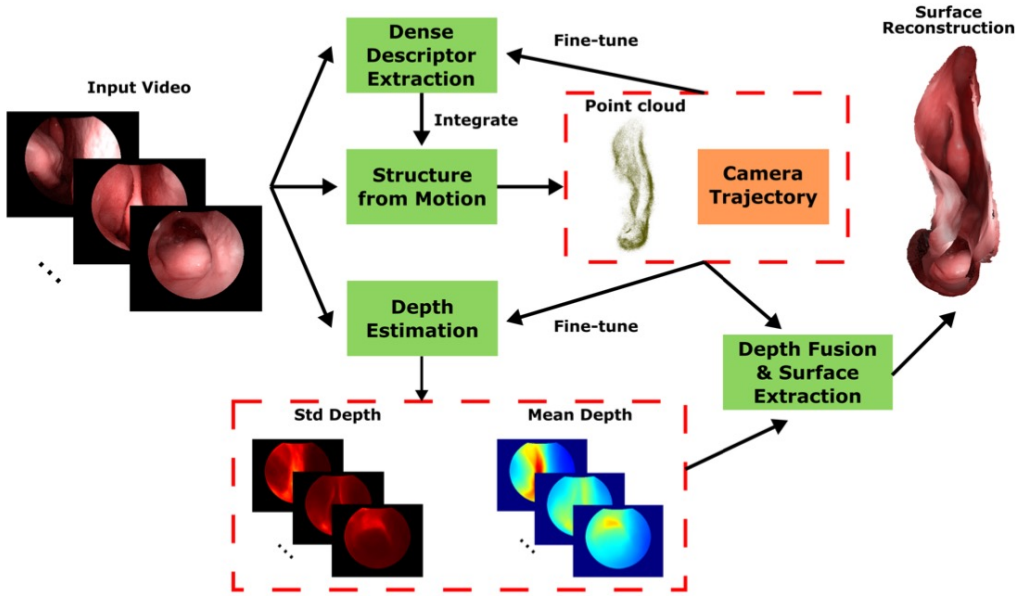
Relevance: Pipeline to generate patient-specific 3D reconstruction

Original Video | Reconstruction Fly-through | Depth rendering

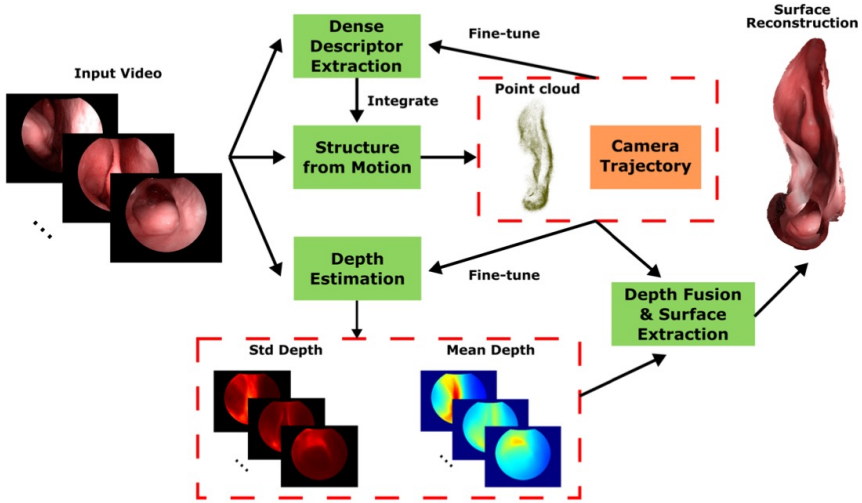
Technical Approach

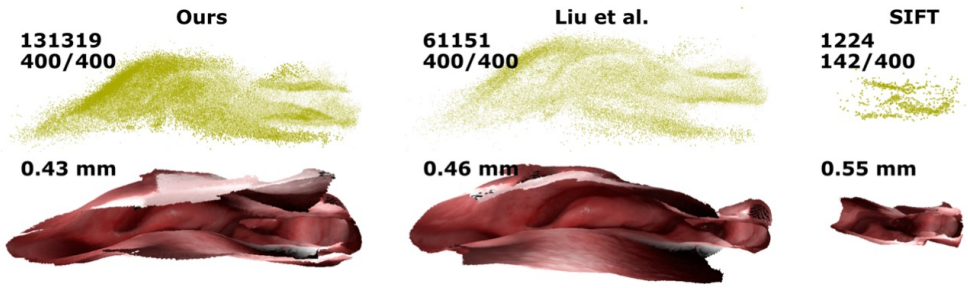
- Structure from Motion (SfM) with Dense Descriptor [2]
- Depth Estimation [3]
- Depth Fusion and Surface Extraction



Technical Approach

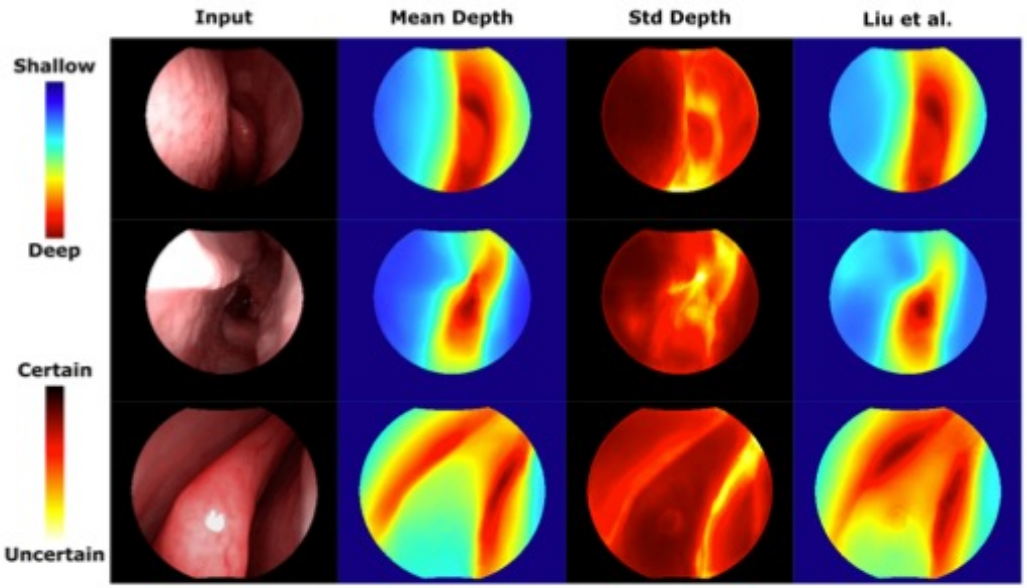
- Structure from Motion (SfM) with Dense Descriptor [2]
  - *Self-supervised learning module*
  - *Initial SfM with SIFT descriptor as supervisory signal*
  - *Dense feature matching to produce correspondences*
- Depth Estimation [3]
- Depth Fusion and Surface Extraction





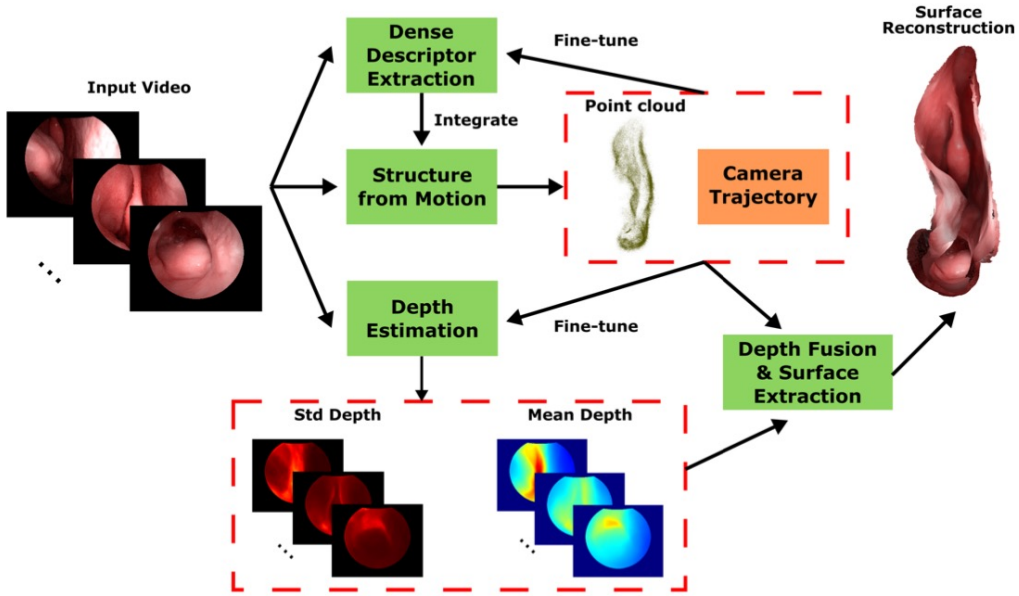
Technical Approach

- Structure from Motion (SfM) with Dense Descriptor [2]
- Depth Estimation [3]
  - *Self-supervised learning module*
  - *Guidance from sparse SfM*
  - *Probabilistic model based on Gaussian distribution*
- Depth Fusion and Surface Extraction



Technical Approach

- Structure from Motion (SfM) with Dense Descriptor [2]
- Depth Estimation [3]
- Depth Fusion and Surface Extraction
  - *Method based on truncated signed distance function* [4]
  - *SfM results for rescaling*
  - *Marching Cubes method* [5]

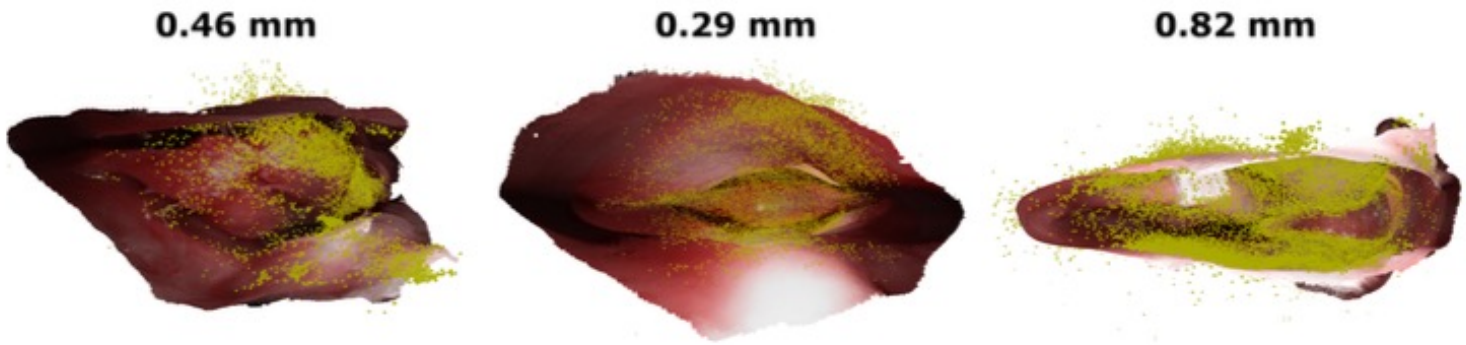


Comparison with SfM

- Sparse SfM results used for self-supervisory signal
- Evaluate consistency in pipeline
- Rescaled sparse SfM based on ground-truth CT

Results:

- Minimal discrepancies
- Average point-to-mesh distance = 0.34 (± 0.14) mm



Consistency against Video Variation

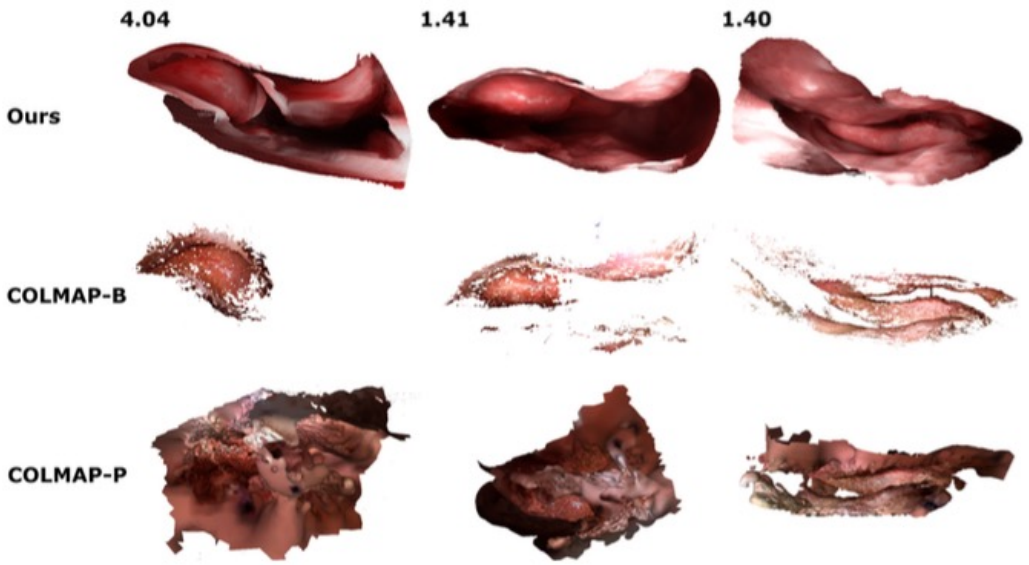
- Reconstruction must be robust to variations in video capture
  - *Ex. camera speed*
- Sub-sampling of frames from input video
  - *Randomly selected 7 frames for every 10 consecutive frames*
- Evaluated reconstruction from subset of frames for consistency

Results

- Average residual error = 0.21 (± 0.10) mm

Comparison with COLMAP Methods

- Ball-pivoting method [6]
- Registered proposed reconstruction with COLMAP-B



Results

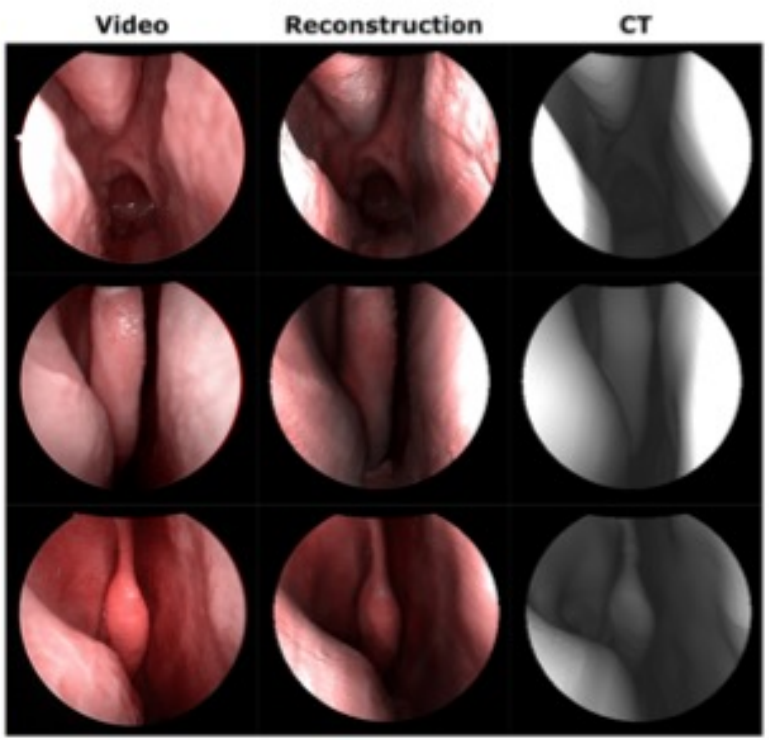
- Average residual distance = 0.24 (± 0.08) mm
- Runtime: 127 minutes (COLMAP: 778 minutes)

Comparison with CT

- Evaluate proposed reconstruction as CT alternative
- Registered camera poses from SfM used as origin
- Compared cross-sectional areas

Results:

- Reported relative differences
- Average residual error = 0.69 (± 0.14) mm



Critical Review

Pros

- Evaluated consistency of modules throughout the pipeline
- Reported metrics relevant towards use in clinical setting
- Achieved sub-millimeter differences and errors

Cons

- Unclear how camera poses were registered to CT space
- Cross-sectional planes used to compare to ground truth CT anatomy

Relevance

- Framework will enable further research on this pipeline
- Provide baseline evaluation and analysis on consequent changes
- Registration with modified anatomies

References

[1] Liu, X., Stiber, M., Huang, J., Ishii, M., Hager, G.D., Taylor, R.H., Unberath, M.: Reconstructing sinus anatomy from endoscopic video – towards a radiation-free approach for quantitative longitudinal assessment. In: Martel, A.L., Abolmaesumi, P., Stoyanov, D., Mateus, D., Zuluaga, M.A., Zhou, S.K., Racoceanu, D., Joskowicz, L. (eds.) Medical Image Computing and Computer Assisted Intervention – MICCAI 2020, pp. 3–13. Springer, Cham (2020)

[2] Liu, X., et al.: Extremely dense point correspondences using a learned feature descriptor. In: Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, pp. 4847–4856 (2020)

[3] Liu, X., Sinha, A., Ishii, M., Hager, G.D., Reiter, A., Taylor, R.H., Unberath, M.: Dense depth estimation in monocular endoscopy with self- supervised learning methods. IEEE transactions on medical imaging 39(5), 1438–1447 (2019)

[4] Curless, B., Levoy, M.: A volumetric method for building complex models from range images. In: Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques, pp. 303–312 (1996)

[5] Lorensen, W.E., Cline, H.E.: Marching cubes: a high resolution 3D surface construction algorithm. ACM SIGGRAPH Comput. Graph. 21, 163–169 (1987)

[6] Bernardini, F., Mittleman, J., Rushmeier, H., Silva, C., Taubin, G.: The ball- pivoting algorithm for surface reconstruction. IEEE Trans. Vis. Comput. Graph. 5(4), 349–359 (1999)