Project 12

Evaluation of CT Registration for Image-based Sinus Reconstruction

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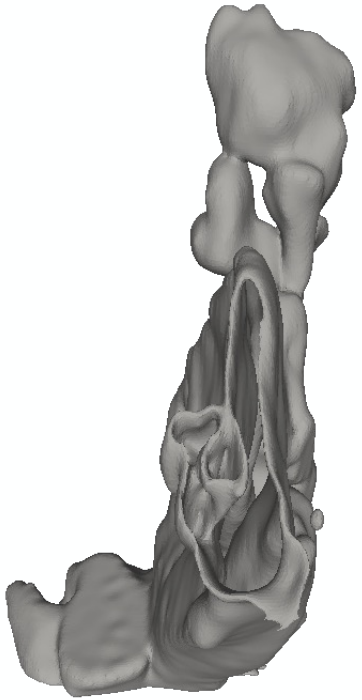
Mentors: Dr. Roger Soberanis, Dr. Mathias Unberath

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

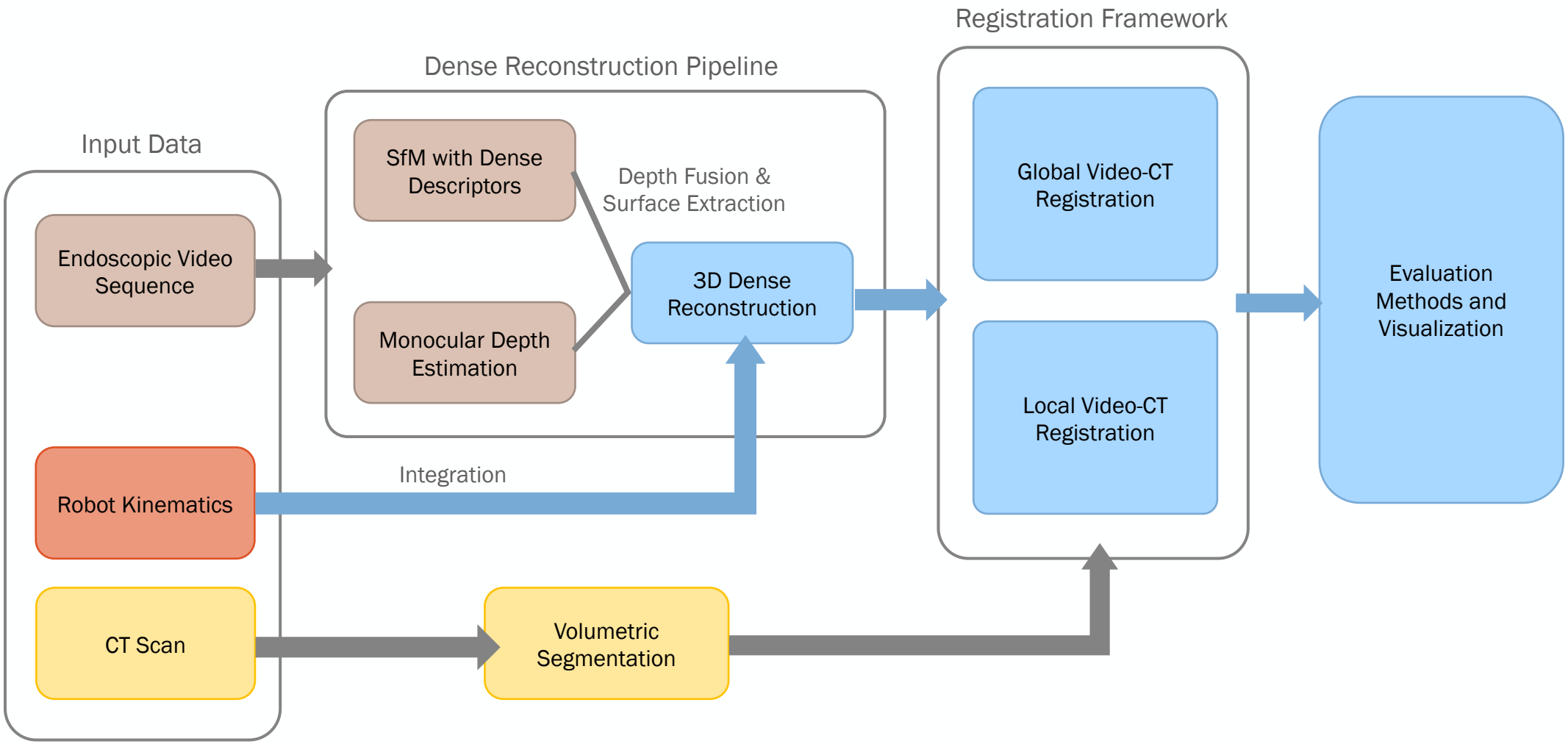
Key Deliverables

	Activities	Deliverables
Minimum	Data pre-processing: generate dense reconstructions and perform CT segmentation	3D Dense Reconstruction and Segmented CT scans
	Integrate rigid registration methods (ICP, IMLP and variations) for global registration	Code and documentation
	Implement data processing steps to isolate local regions and apply rigid registration methods	Code and documentation
	Report error evaluation between dense reco and CT ground truth with visualizations	Report of evaluated data
Expected	Adjust depth fusion step in pipeline to account for uncertainties in estimation	Code and documentation
	Evaluation of new dense reconstruction	Resulting dense reconstruction and comparison metrics
Maximum	Integrate robot kinematics into registration method	Code and documentation
	Evaluation of new dense reconstruction	Resulting dense reconstruction and comparison metrics

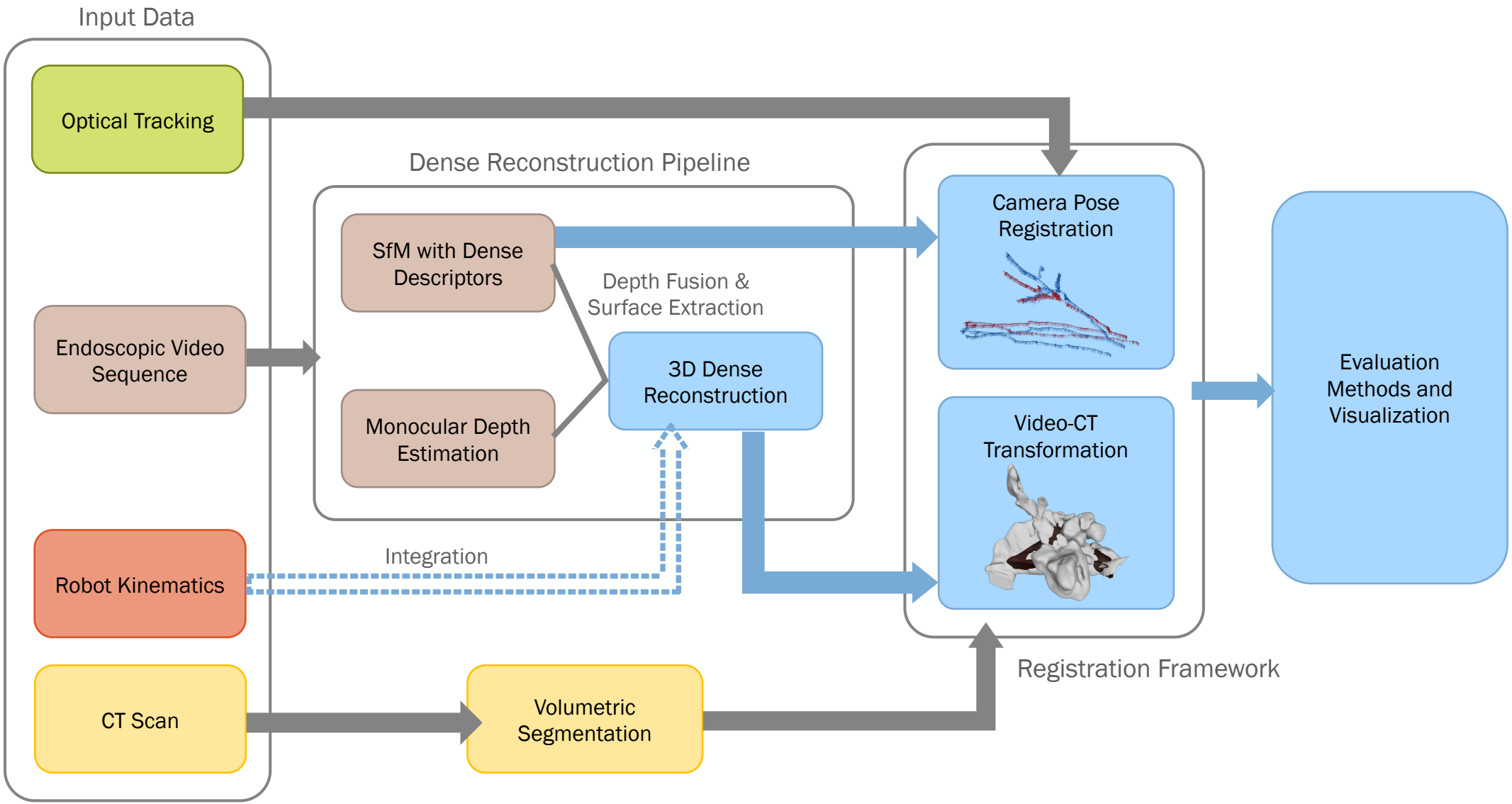
Key Deliverables

	Activities	Deliverables	Status
Minimum	Data pre-processing: generate dense reconstructions and perform CT segmentation	3D Dense Reconstruction and Segmented CT scans	Complete
	Integrate rigid registration methods (ICP, IMLP and variations) for registration	Code and documentation	Complete
	~~Implement data processing steps to isolate local regions and apply rigid registration methods~~	~~Code and documentation~~	Cancelled
	Error evaluation metrics between dense reco and CT ground truth with visualizations	Report of evaluated data	Ongoing
Expected	Adjust depth fusion step in pipeline to account for uncertainties in estimation	Code and documentation	In Progress
	Evaluation of new dense reconstruction	Resulting dense reconstruction and comparison metrics	Not Started
Maximum	*Processing and evaluation of dense reconstructions of remaining cadaveric data*	*Report of metrics*	In Progress
	Transactions in Medical Imaging Paper Extension (for MICCAI 2020)	*Paper*	Not Started
	Integrate robot kinematics into registration method and evaluate	Comparison metrics	(Future Work)

Old Technical Approach

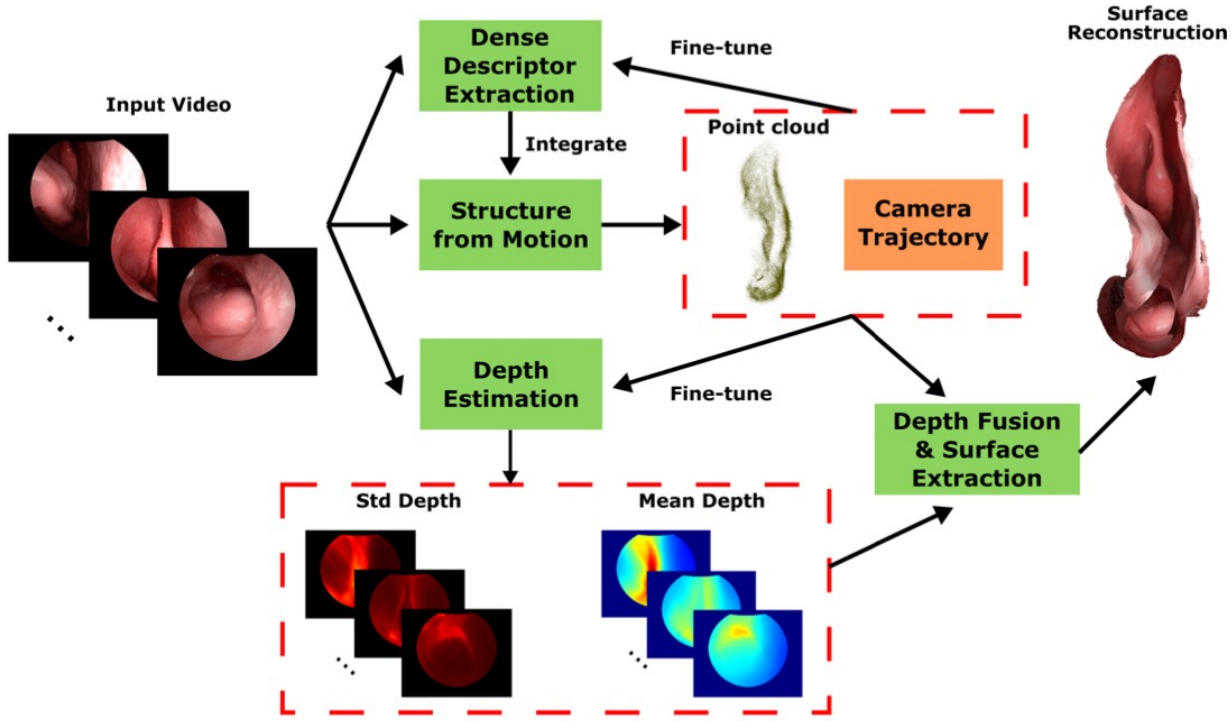


Updated Technical Approach



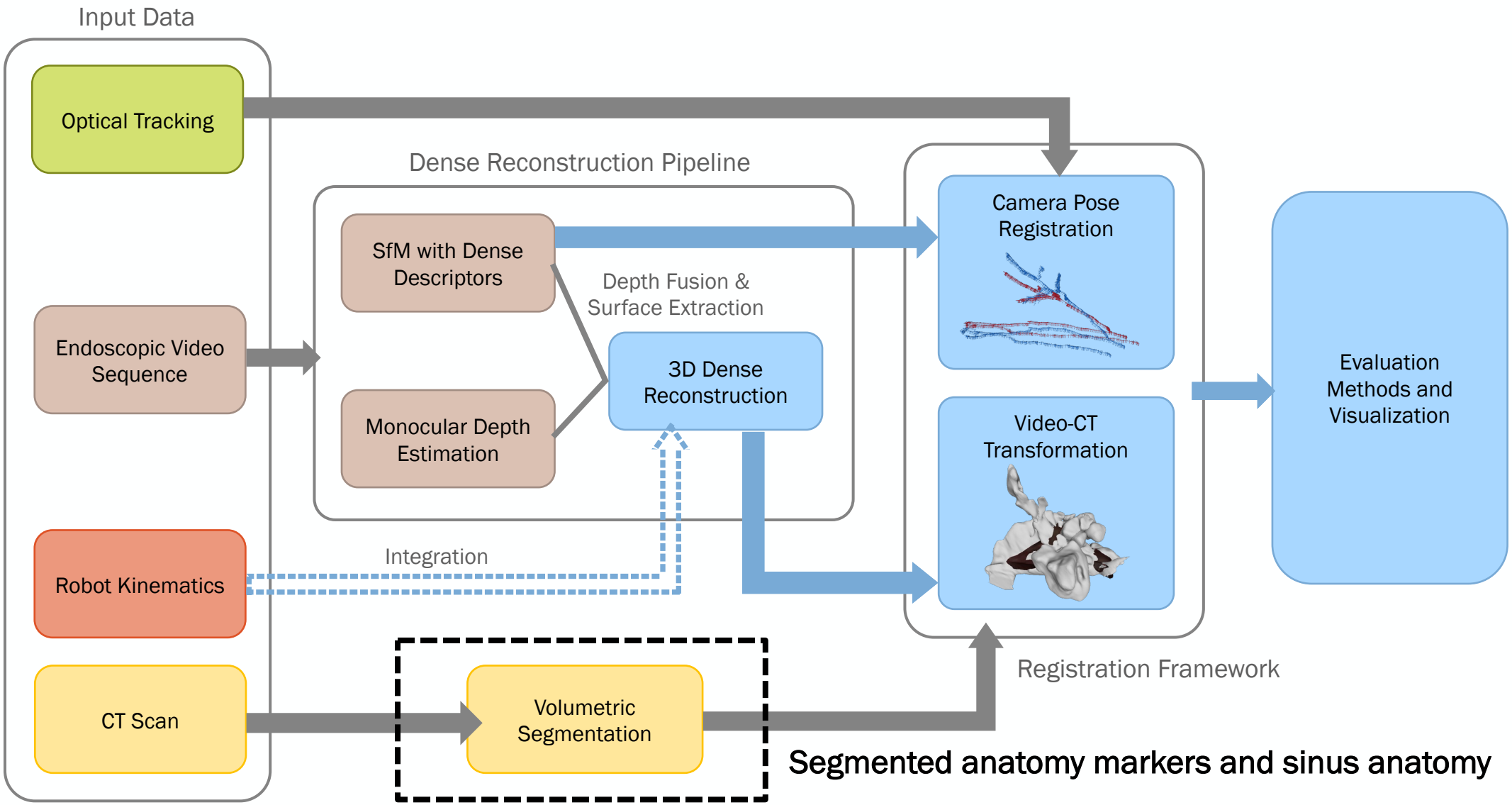
Dense Reconstruction Pipeline [1]

- Structure from Motion (SfM) with Dense Descriptor [2]
  - *Point cloud of anatomy*
  - *Estimated camera trajectories for each input frame*
- Depth Estimation [3]
  - *Standard deviation as depth uncertainties*
- Depth Fusion and Surface Extraction
  - *Fuses point cloud to triangle mesh based on depth*



Liu, Xingtong, et al. "Reconstructing Sinus Anatomy from Endoscopic Video -- Towards a Radiation-Free Approach for Quantitative Longitudinal Assessment" Medical Image Computing and Computer Assisted Intervention (2020)

Updated Technical Approach



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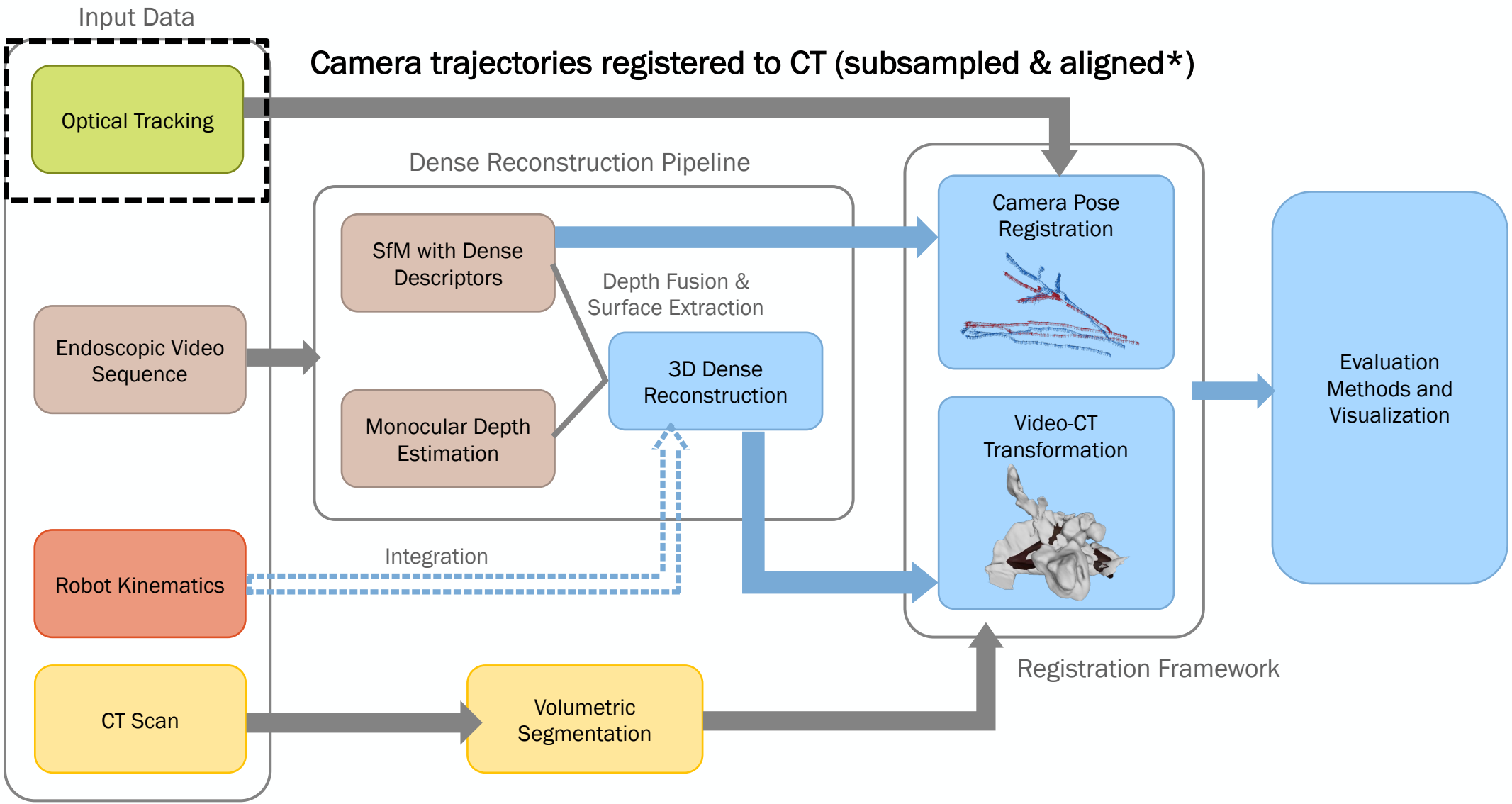

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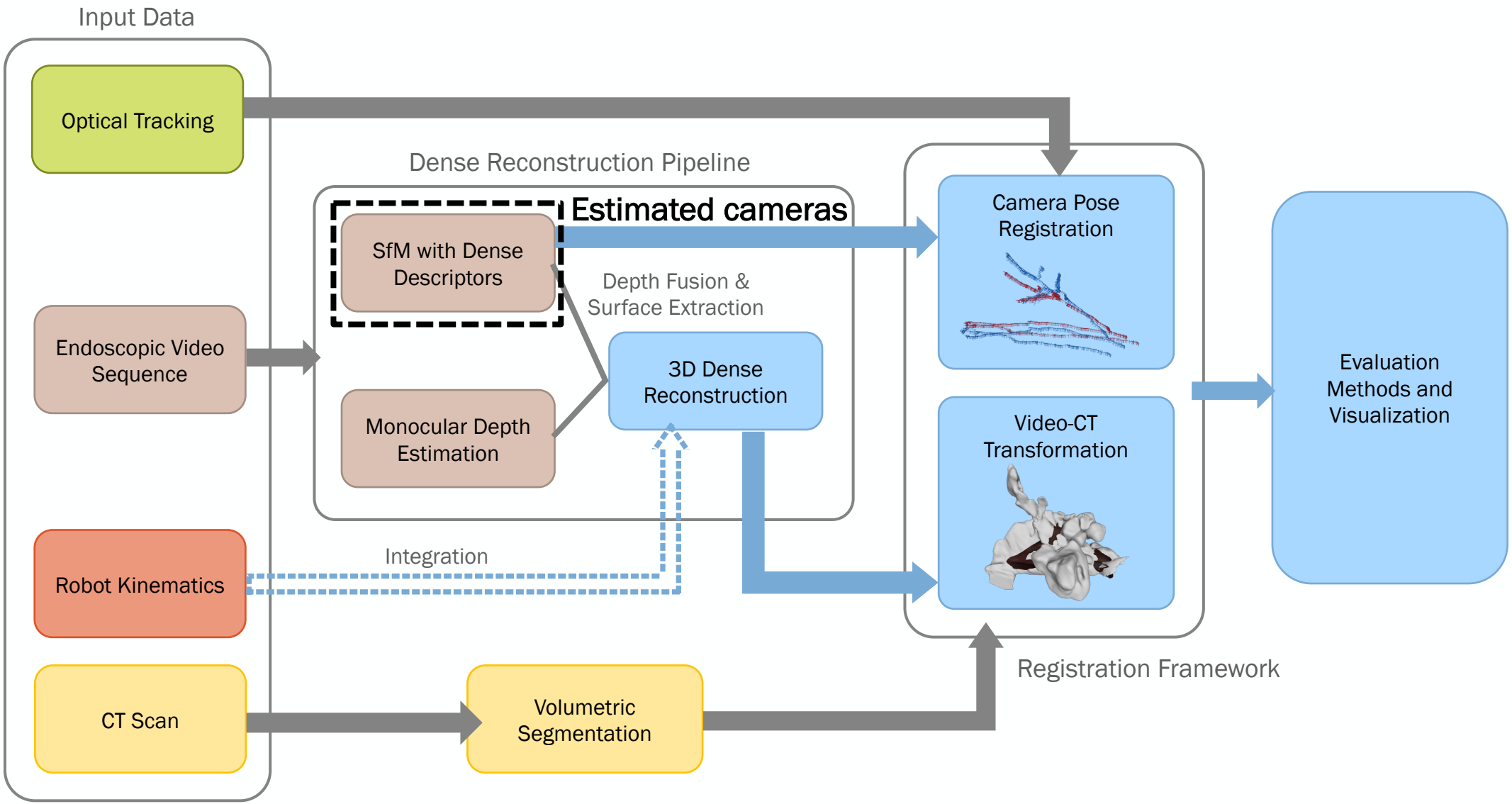

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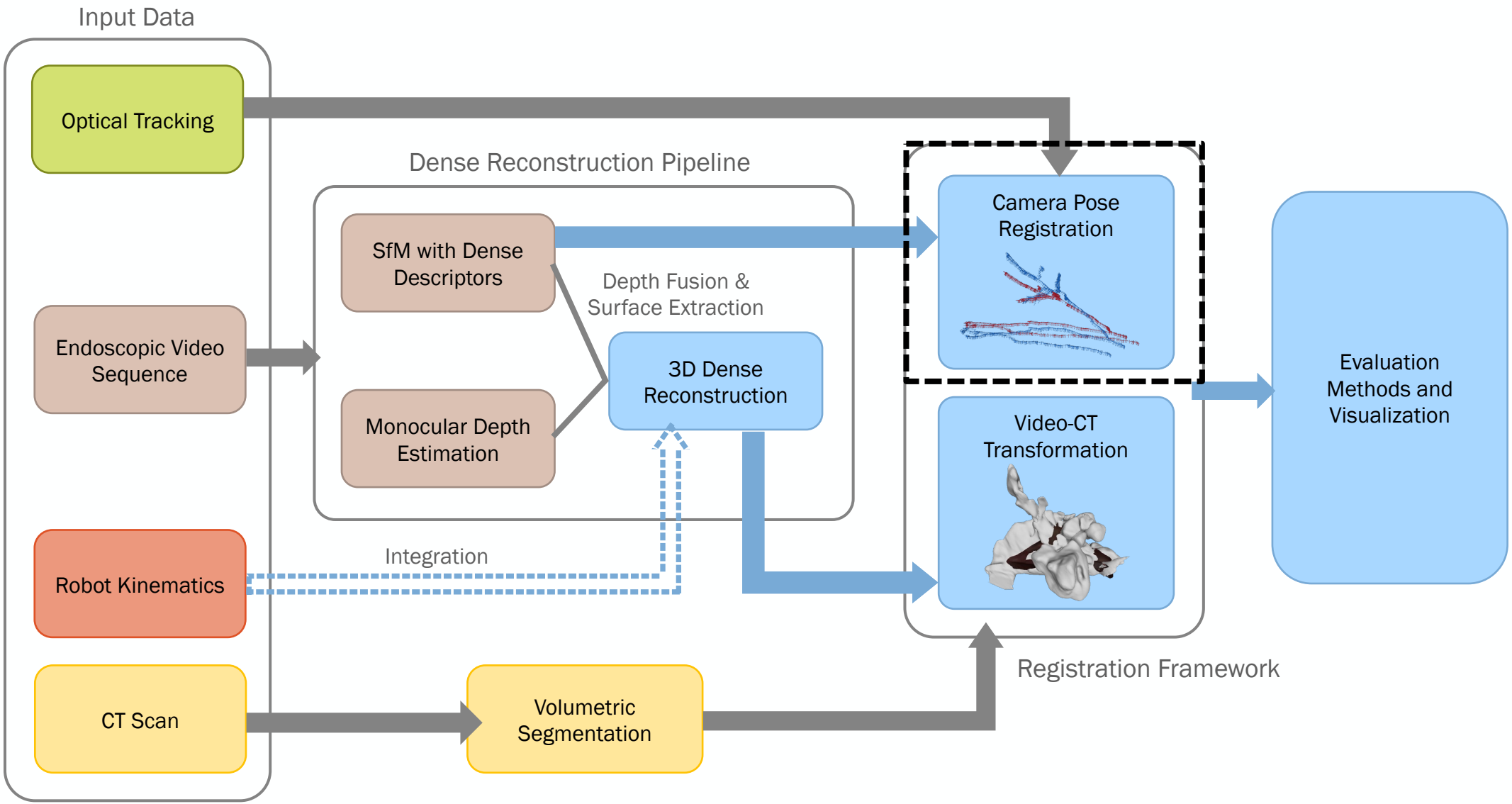

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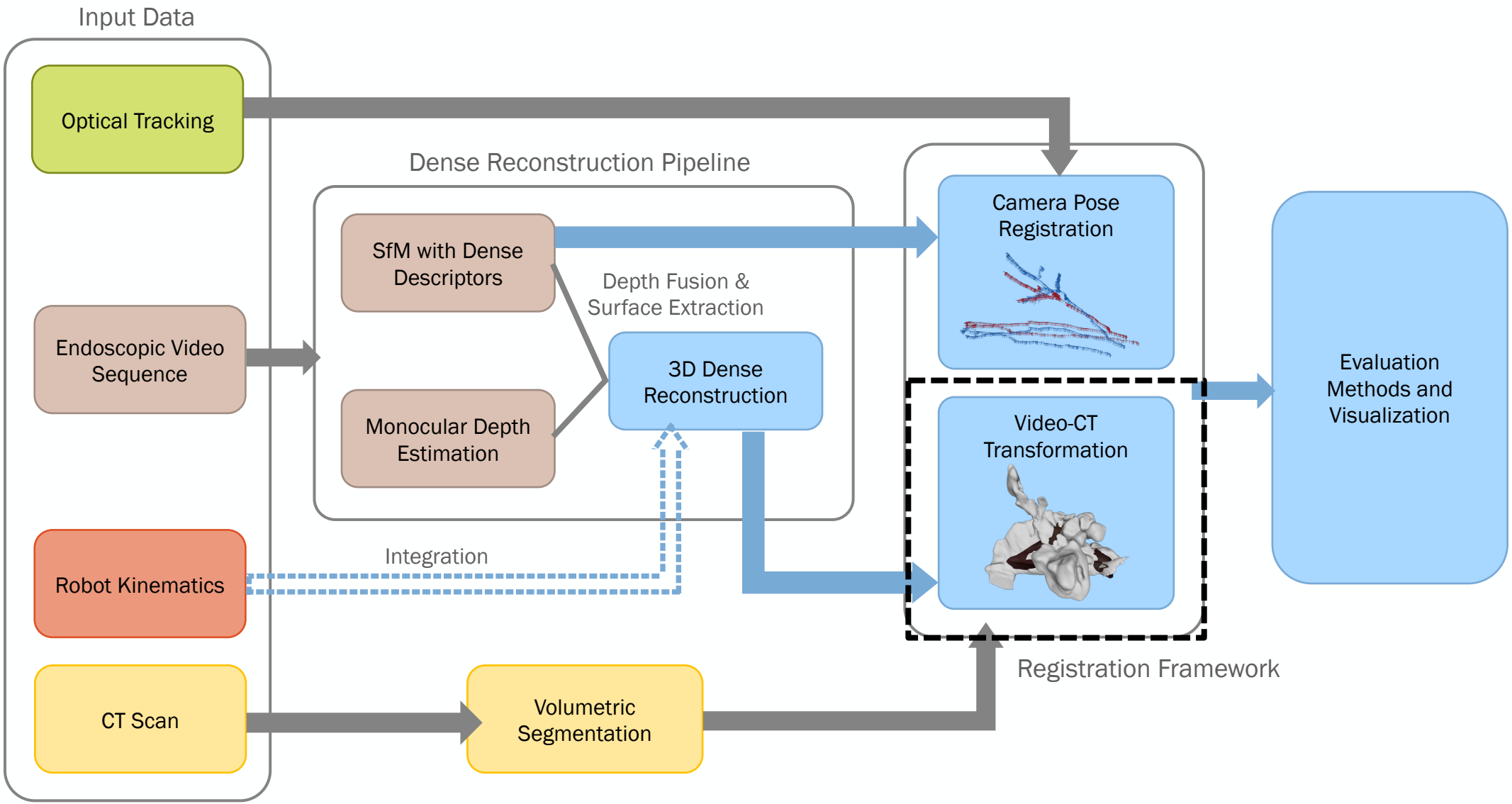
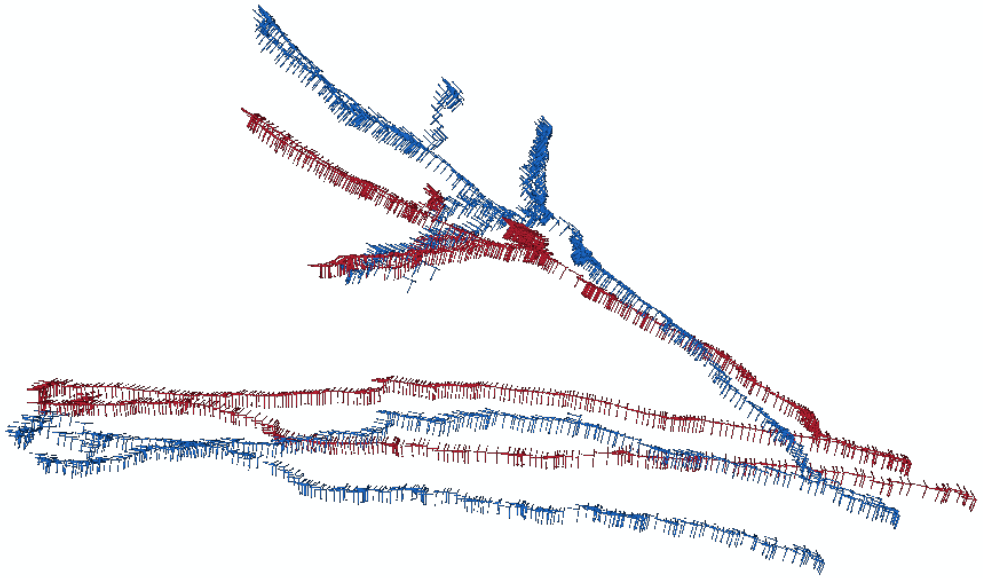
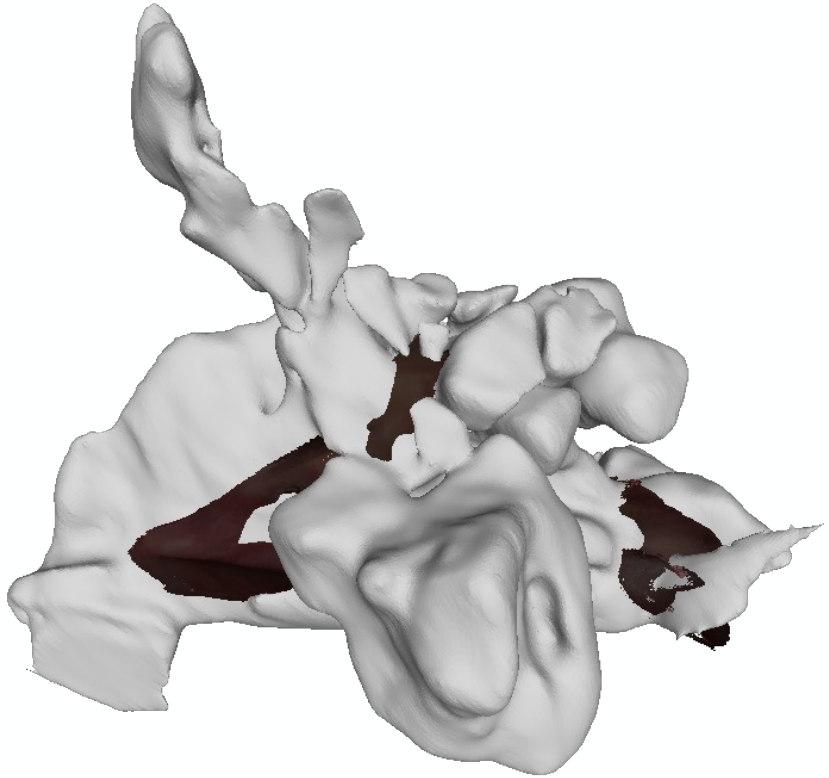


Preliminary Results

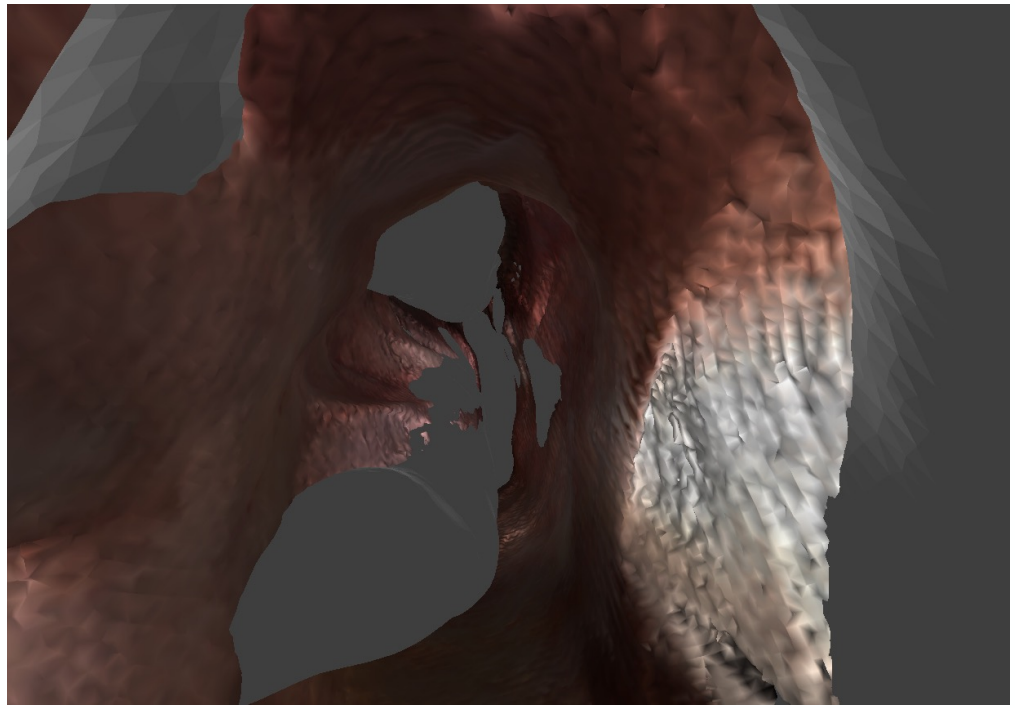


Registered Camera Trajectories



Transformed Meshes

Preliminary Results



Evaluation Metric

MICCAI 2020 Paper

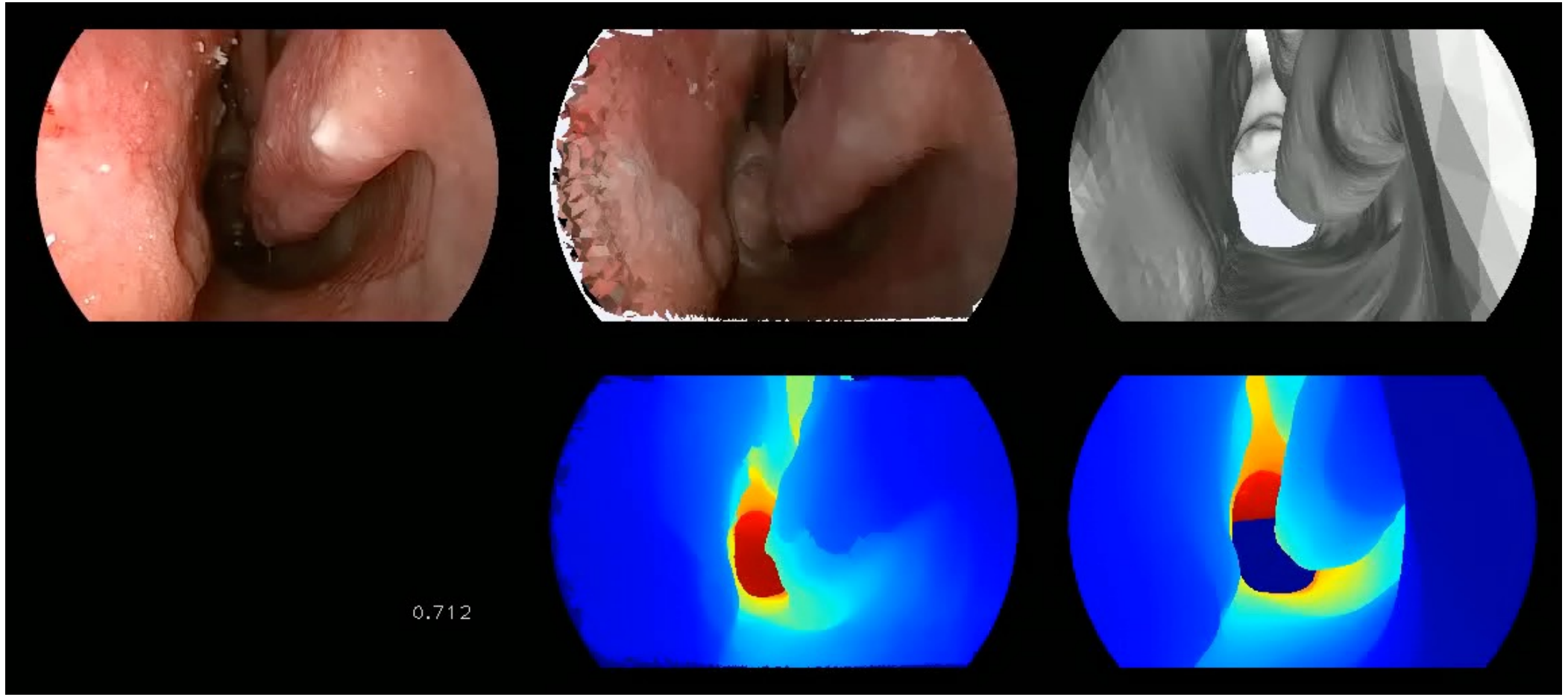
- Reported residual error between the registered surface reconstruction and the CT model
- Relative difference between cross-sectional areas based on SfM camera trajectories
- Not reproducible on new data

Scale Invariant Depth Error [4]

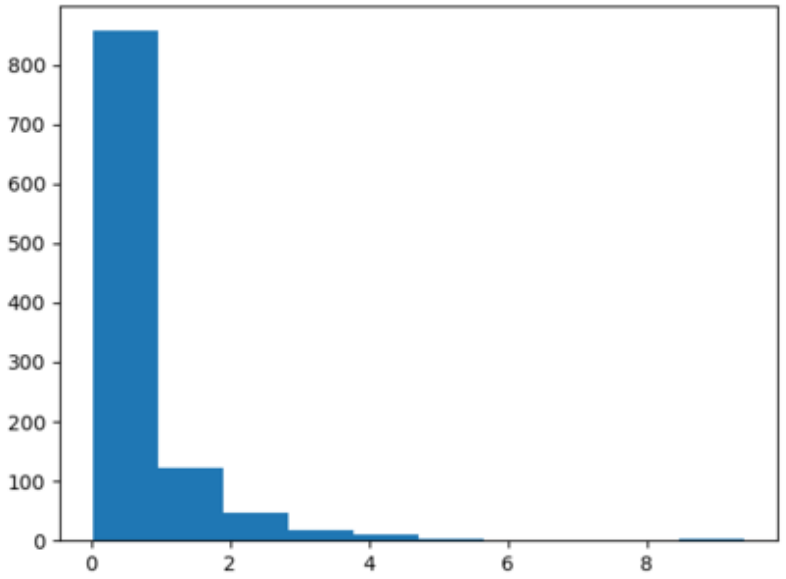
$$D(y, y^*) = \frac{1}{n}\sum_i d_i^2 - \frac{1}{n^2}\left(\sum_i d_i\right)^2 \qquad d_i = \log y_i - \log y_i^*$$

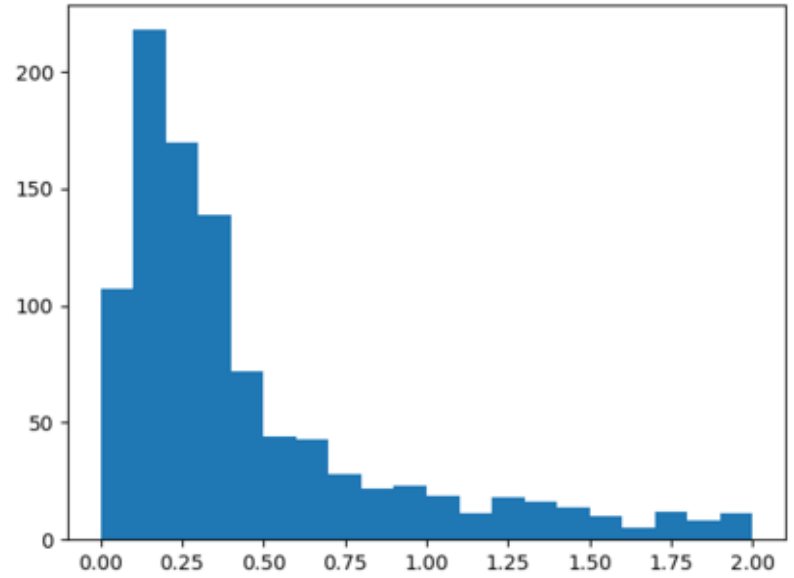
Recent Results: Depth Rendering

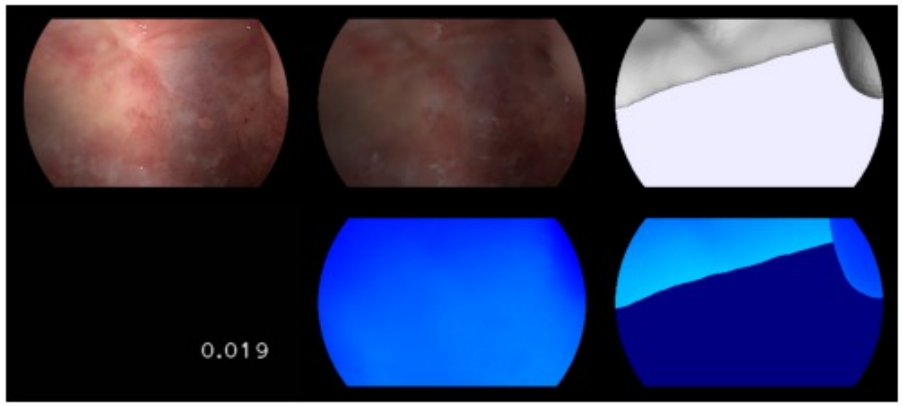
Average Error = 0.636

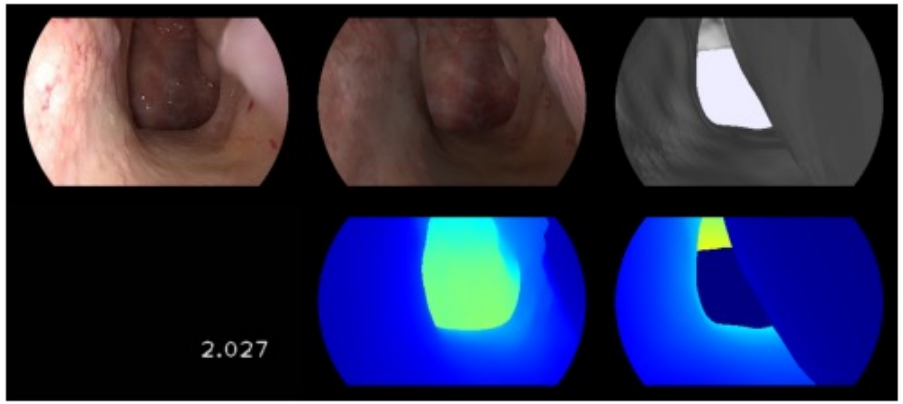


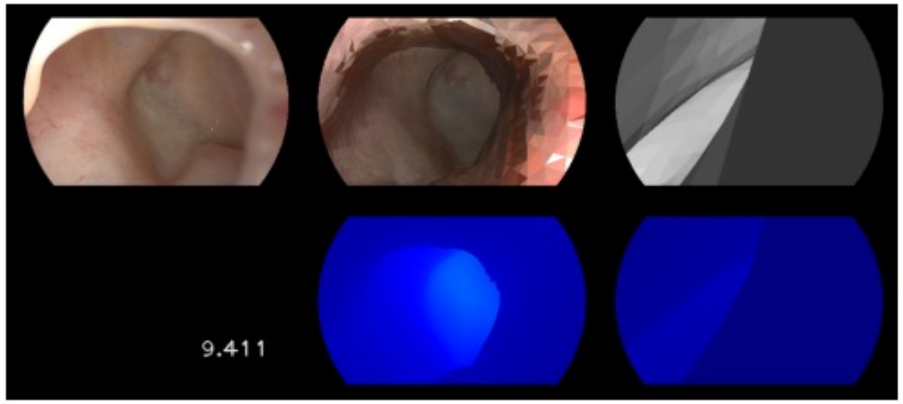
Recent Results: Depth Rendering





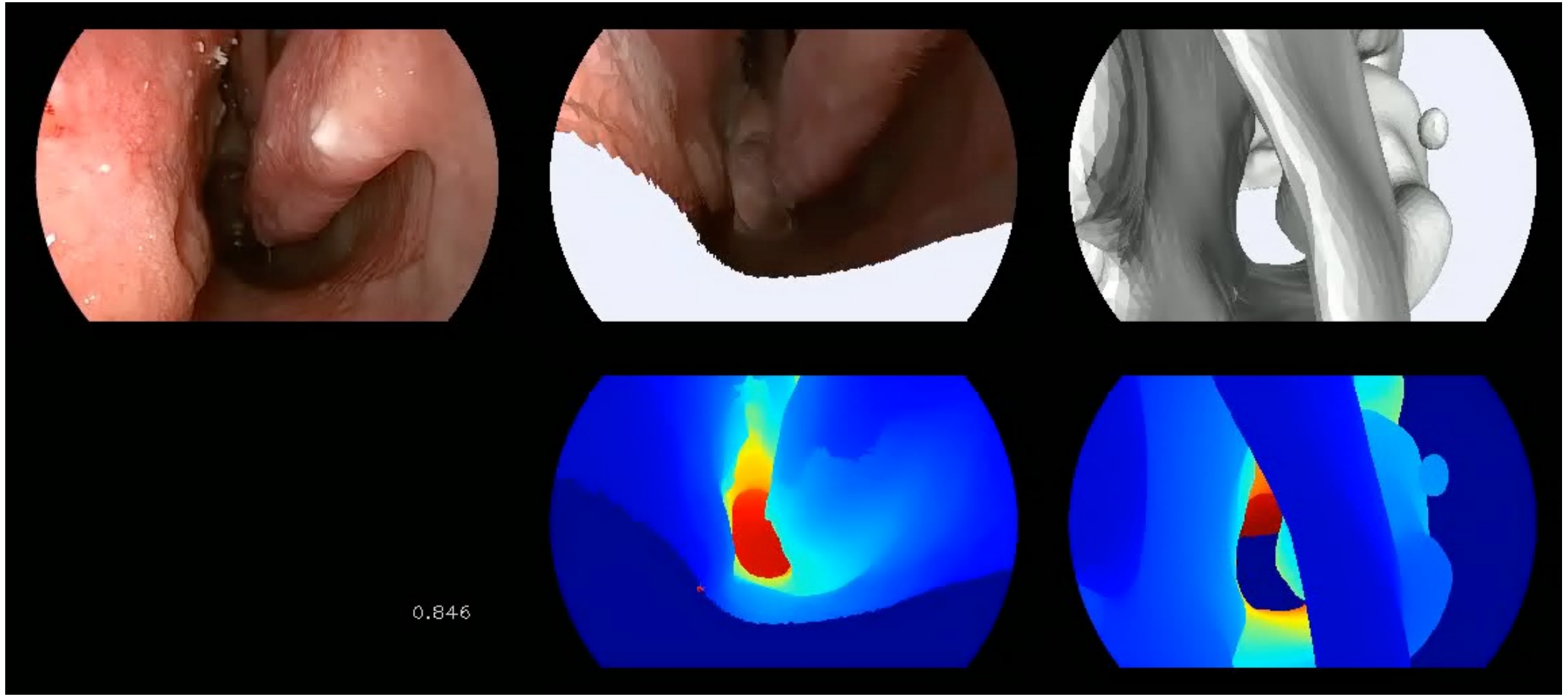




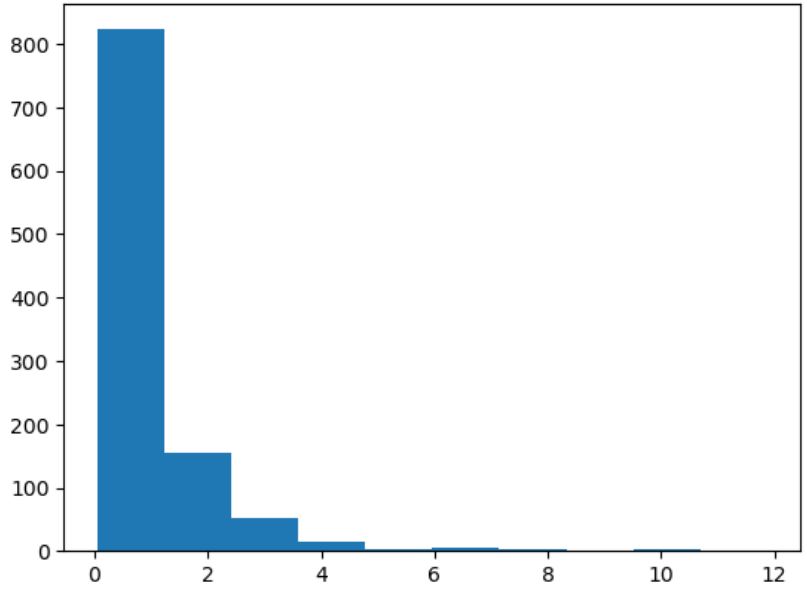


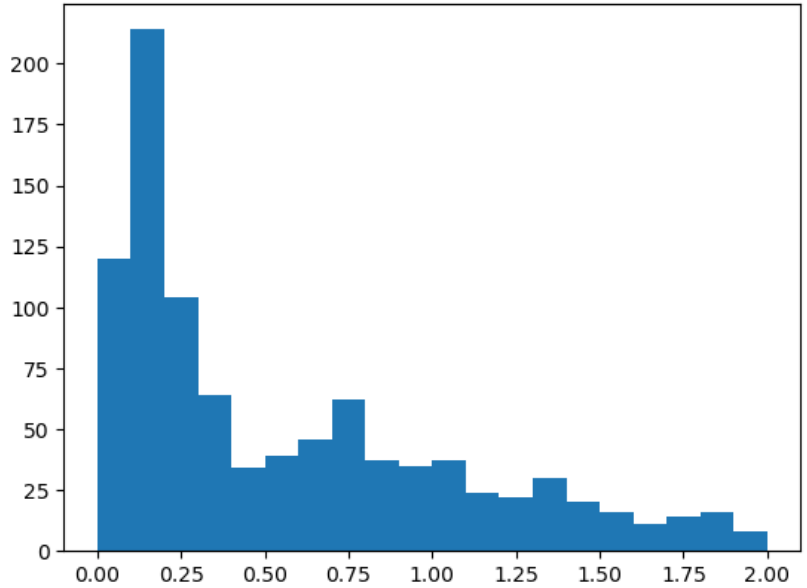
Recent Results: Alternate Camera Path

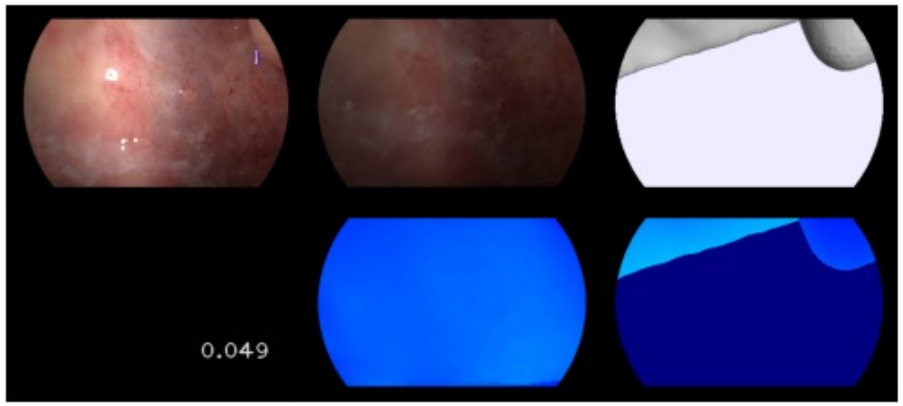
Average Error = 0.861

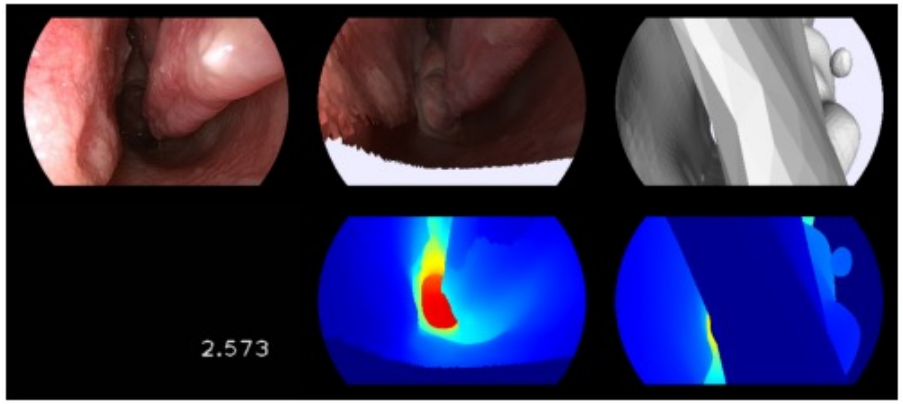


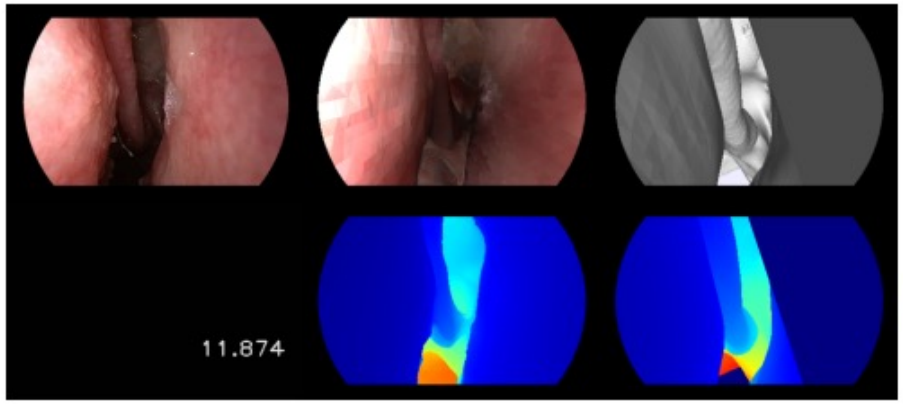
Recent Results: Alternate Camera Path











Next Steps

- Evaluate alternate orientations in both camera paths
  - *Focus on point in center of both meshes*
- Existing code for weighting fusion step by uncertainties
  - *Analyze distribution more closely*
  - *Evaluate multiple methods for integration*
- Prepare additional data
  - *6 patients (left and right nostrils)*
  - *Local reconstructions (subset of input image sequence)*

Dependencies

Dependency	Need	Status	Follow-up	Contingency Plan
Computing Power	Run dense reco pipeline	Ready to use	ARCADE lab workstation	N/A
Dense Reconstruction Pipeline	Generate 3D sinus reconstructions	Ready to use	N/A	Available on github
cisstICP Library	Implementation of registration methods	Installed	N/A	Available on github
3D Slicer	Segment CT scans	Installed	N/A	N/A
Sinus Data	Input for dense reconstruction pipeline	Available	N/A	Additional cadaveric data collection sessions
CT scans and Optical Tracking	Ground truth	Available	N/A	Additional cadaveric data collection sessions
Robot kinematic data	Integration into reconstruction pipeline	Available	N/A	Additional cadaveric data collection sessions

Old Project Timeline

Milestones	February				March				April				May	
	6	13	20	27	6	13	20	27	3	10	17	24	1	8
1. Setup and Data Pre-processing														
1.1 Project Proposal														
1.2 cisstICP Setup														
1.3 Generate 3D Reconstructions														
1.4 Segment CT Scans														
2. Implementation														
2.1 Global Registration														
2.2 Isolate anatomical regions of interest														
2.3 Local Registration														
2.4 Evaluation Metrics and Visualization														
3. Influence of Uncertainties														
3.1 Analyze distribution of depth estimation														
3.2 Adjust for uncertainties in depth fusion														
3.3 Report Evaluation Metrics and Visualization														
4. Robot Kinematics														
4.1 Integrate robotic data into registration														
4.2 Report Evaluation Metrics and Visualization														
5. Writing														
5.1 Finalize code and documentation														
5.2 Prepare final report														

Updated Project Timeline

Milestones	February				March				April				May	
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1. Setup and Data Pre-processing														
1.1 Project Proposal														
1.2 cisstICP Setup														
1.3 Generate 3D Reconstructions														
1.4 Segment CT Scans														
2. Rigid Registration Methods														
2.1 Registration framework implementation														
2.2 ~~Isolate anatomical regions of interest~~														
2.3 ~~Local Registration~~														
2.4 Evaluation Metrics and Visualization														
3. Influence of Uncertainties														
3.1 Analyze uncertainties in depth fusion step														
3.2 Integrate probabilistic model														
3.3 Report Evaluation Metrics and Visualization														
4. Transactions in Medical Imaging Paper														
4.1 Process additional data														
4.2 Draft Paper														
5. Final Report Writing														
5.1 Finalize code and documentation														
5.2 Prepare final report														

Roles and Responsibilities

Team:

Jan Mangulabnan
PhD Student

Timo Teufel – assist with data pre-processing
Visiting Graduate Student in ARCADE Lab

Mentors:

Roger Soberanis, *PhD*
Postdoc in ARCADE Lab

Mathias Unberath, *PhD*
Assistant Professor in Computer Science

Management Plan

- Working with Roger daily (in B05)
- Bi-weekly meetings with Mathias
- Weekly lab meetings: progress reports

Communication

- Slack / Email

Data Management

- Currently stored on ARCADE lab workstation and personal Github repository
  - *Migrate to github repository (SinusEndoscopy)*
- Data stored on Sinus hard drive

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] Eigen, D., Puhrsch, C., Fergus, R.: Depth map prediction from a single image using a multi-scale deep network. Advances in neural information processing systems 27 (2014)