Neural Rendering for Stereo 3D Reconstruction of Deformable Tissues in Robotic Surgery

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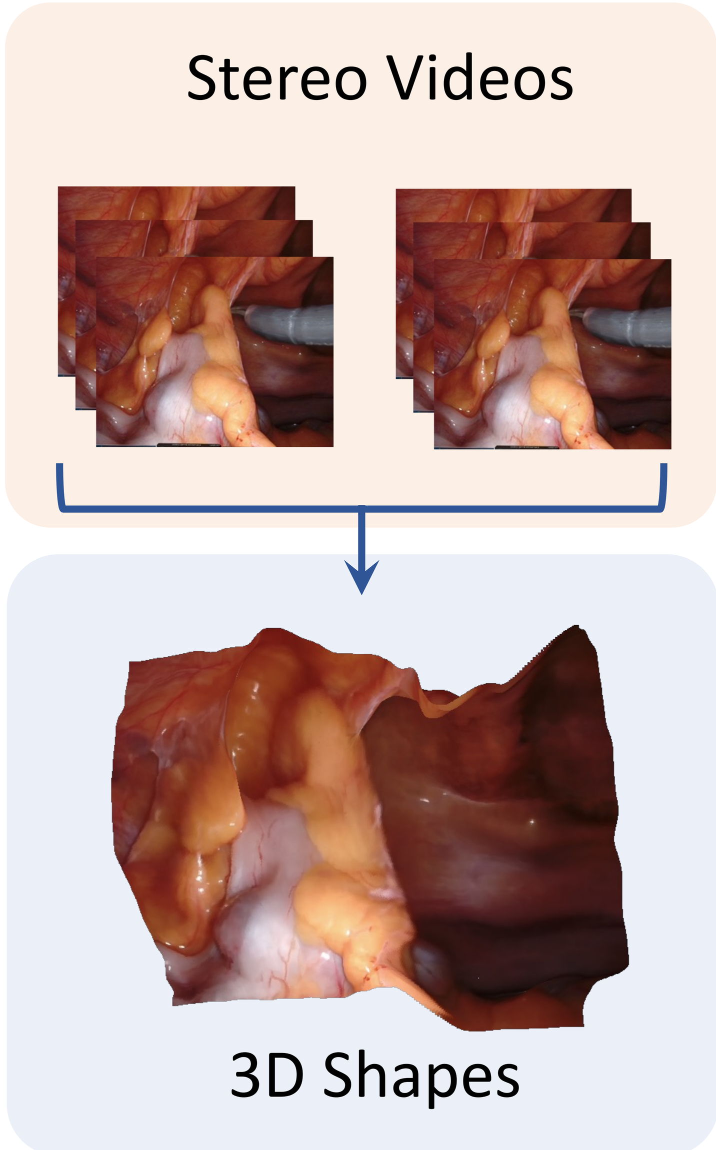
Introduction

Background:

Surgical reconstruction plays an important role in Minimally Invasive Surgery (MIS), since it can illuminate many down-stream tasks:

- ❑ Intra-operative navigation.
- ❑ Surgical planning.
- ❑ Context-awareness in MIS.
- ❑ Surgery education.
- ❑ AR guidance in MIS.
- ❑ Surgical visualization.

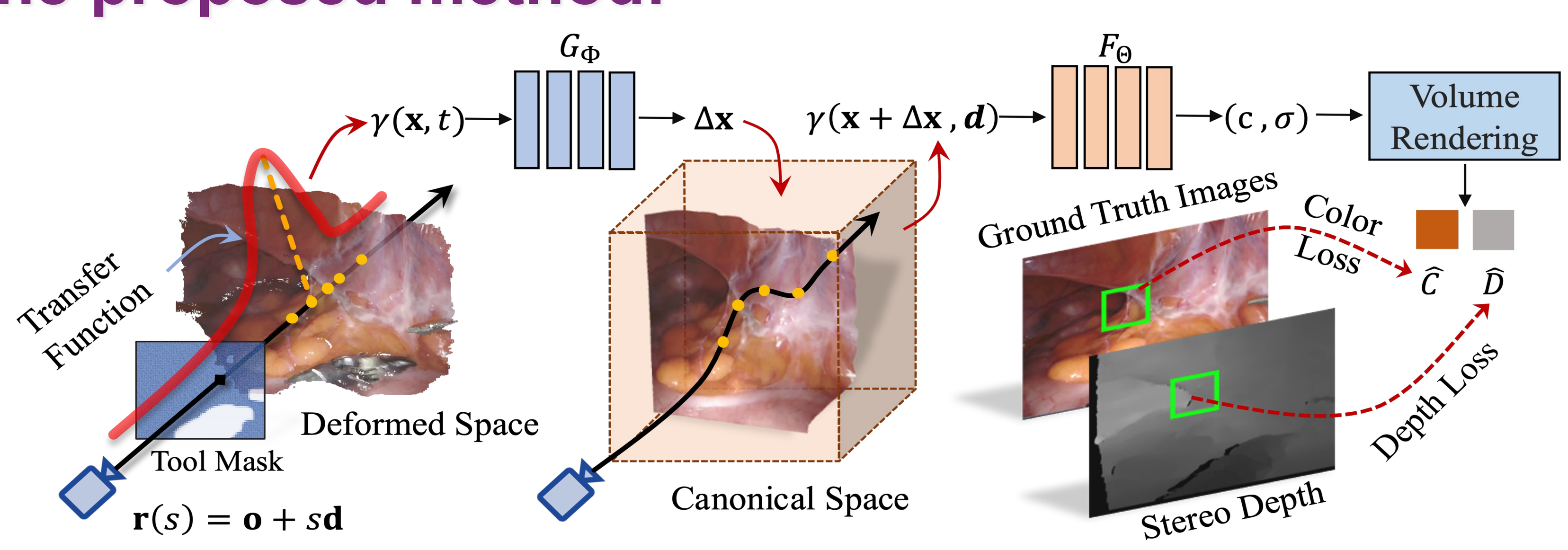


Challenges:

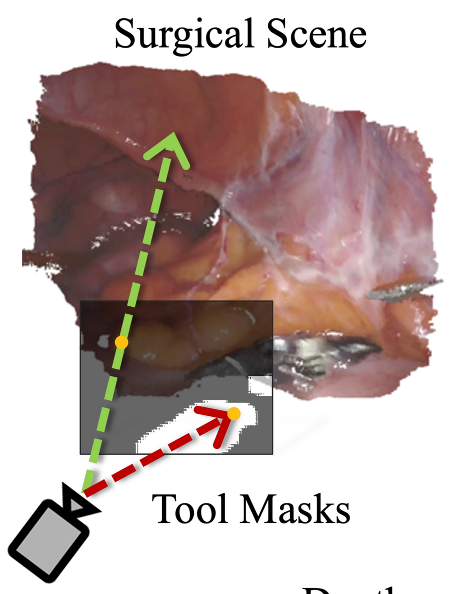
1. Surgical scenes will undergo large deformations.
2. Endoscopic videos show sparse viewpoints due to constrained movement in confined spaces.
3. The surgical tools occlude part of the soft tissues.

Method

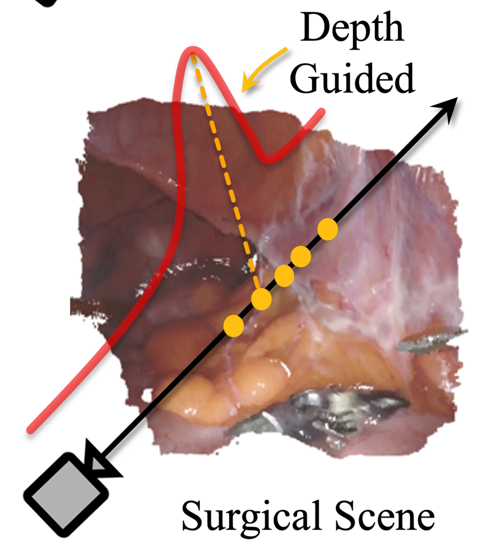
The proposed method:



- Adopt dynamic **neural radiance fields (NeRF)** to represent deformable surgical scenes.



- Design a **new tool-mask guided ray casting** for handling tool occlusion.
  - Reject training rays that shoot towards tool pixels.



- Incorporate **depth-cueing ray marching** and dense **depth-supervised optimization** to impose explicit geometric clues.
  - Concentrate points around tissue surface indicated by stereo depth.
  - Add loss between rendered optical depth and estimated stereo depth.
  - Statistically refine estimated depth to patch corrupt depth.

Experimental Results

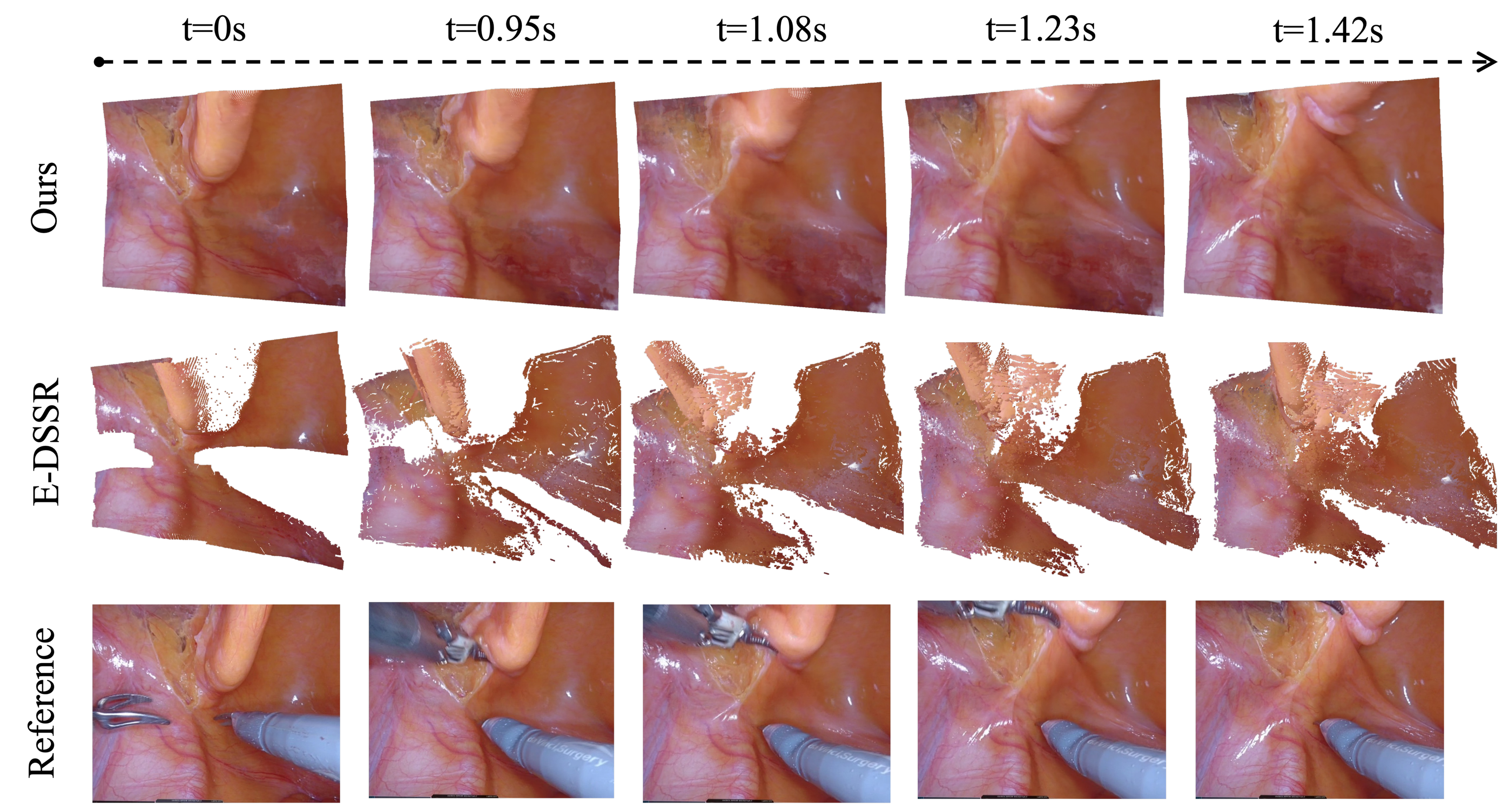
Experiment Setup: Evaluate on robotic surgery stereo videos from 6 cases of our in-house DaVinci robotic prostatectomy data. We choose **E-DSSR** (MICCAI'21) as a strong comparison.

Quantitative Results (Photometric errors):

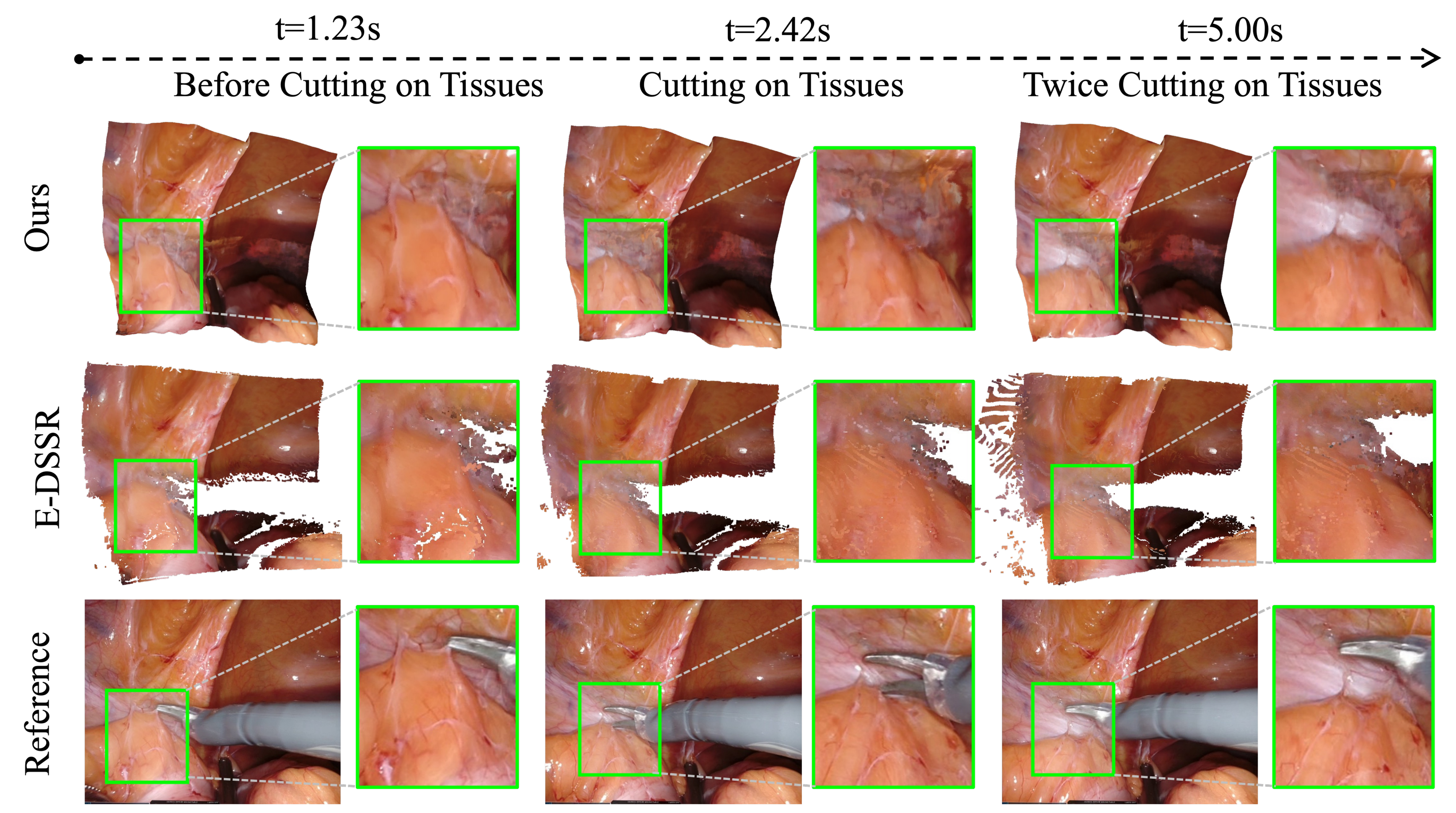
Metrics	Ours	E-DSSR
PSNR	**29.831 ± 2.208**	13.398 ± 1.387
SSIM	**0.925 ± 0.020**	0.630 ± 0.057

Qualitative Results (Visit our project page for more):

Results of "pulling tissues" with large **non-rigid** *deformations*.

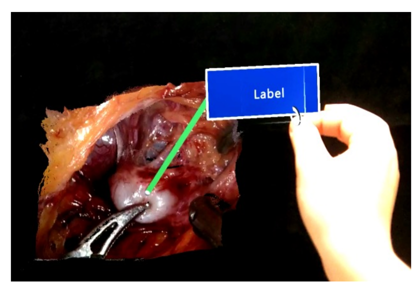


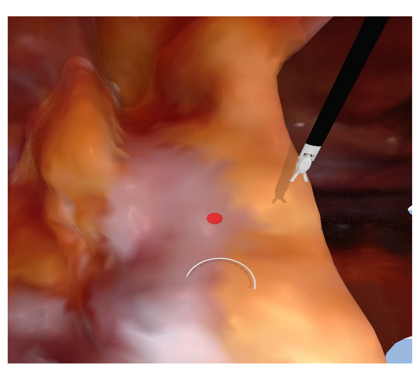
Close-ups results of "cutting tissues twice" with **topology changes**.



Conclusion

Contribution: We have introduced our novel neural rendering-based framework for dynamic surgical scene reconstruction from single-viewpoint binocular captures, addressing complex tissue deformations and tool occlusion.





Applications: **1)** AR/VR immersive surgery education. **2)** Robotic surgery simulation.

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