Occlusion-free 4D Gaussians for Open Surgery Videos Using Multi-Camera Shadowless Lamps

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Abstract

Introduction

- Open surgery videos are valuable for education and research
- However, they often suffer from **occlusions caused by surgeons/staff**

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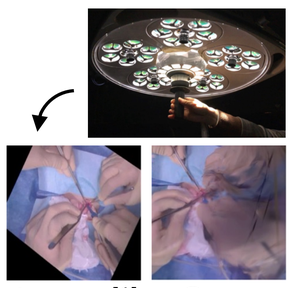
Multi-camera shadowless lamps (McSL) provide multi-view recordings, which can be used to generate occlusion-free views through automatic view switching

Yet, existing approach [1] still suffer from:

- Distorted projections due to 2D image warping
- Missing pixels around image borders
- Limited perspectives



Switch[1] Ours

Our Goal

Generate **editable 3D videos** of open surgeries with **occlusion removal** and **free viewpoint control**

Contributions

- **3D video generation pipeline** for open surgery with McSL using **4D Gaussian Splatting**, enabling both **occlusion removal** and **free-viewpoint** visualization
- **Occlusion removal module** for elimination of occluded regions directly at the level of gaussian splats
- **Synthetic dataset generation** for evaluation of our new task
- **Expert reviews** by medical doctors and their analysis

Method

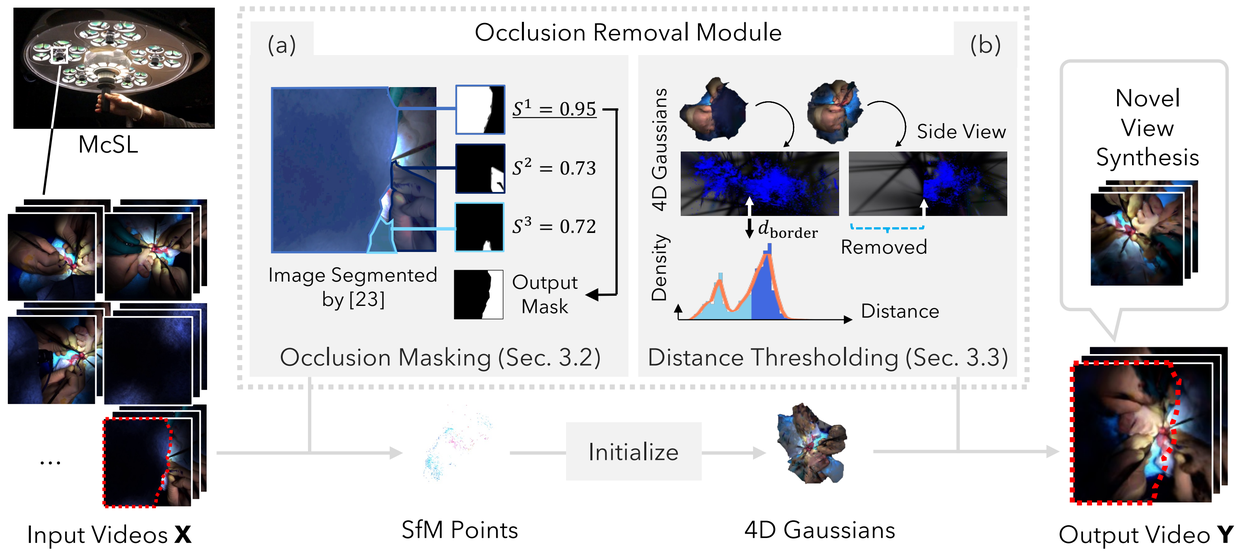
4D Gaussian Splatting (4DGS)-based object removal

Input: Multi-view surgical videos from McSL
Output: Occlusion-free 3D video

Object Removal Strategy (a): Occlusion Masking

Detect occlusion using SAM2 segmentation & filtering using occlusion-specific 4 types of scoring

- S_c **: Convexity Score**
  Measures how convex the shape is, since occluders (e.g., surgeon's head) tend to appear round/convex.
- S_E **: Edge Contact Score**
  Evaluates how much the region touches the image border, since occluders often obscure edges.
- S_I **: Intensity Score**
  Compares brightness of the region against the whole image, because occluders near McSL lamps often appear darker
- S_H **: Hue Consistency Score**
  Checks if color is close to expected (e.g., skin, surgical cap) and uniform



Object Removal Strategy (b): Distance Thresholding

- Analyze Gaussian distributions in 3D space
- Identify and remove clusters corresponding to occluders based on distance separation

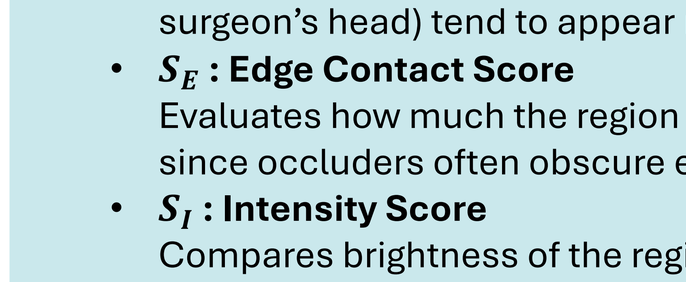
Experiment

Real Dataset

7 types of open surgery videos captured

Virtual Dataset

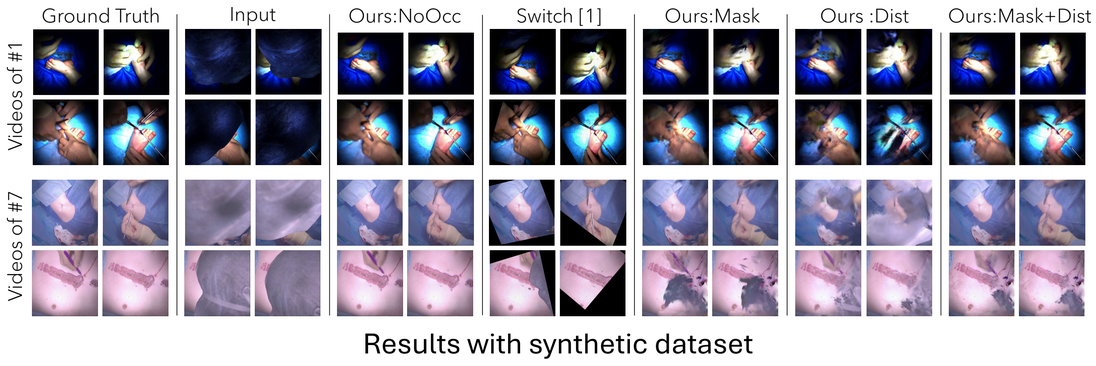
15 polysyndactyly and 10 keloid videos used for synthesis



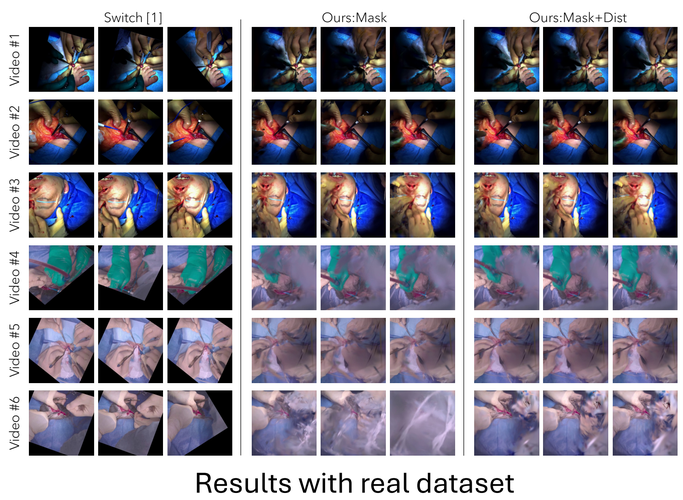
(a) Virtual occlusion regions
(b) Occlusion-less surgical video (ground-truth)
(c) Synthetic data with virtual occlusion (a) overlaid on (b)

Results

- **Switch**: Provides occlusion-less views by switching cameras, but introduces distorted projections, missing pixels, and temporal inconsistencies
- **Ours (Mask)**: Removes major occlusions through segmentation-based masking, though edges can remain unclear
- **Ours (Dist)**: Filters Gaussian clusters by distance, but may mistakenly remove relevant details
- **Ours (Mask+Dist)**: Combines both approaches, producing **cleaner and more stable** results



Results with synthetic dataset



Results with real dataset

Surgeons' Expert Review

Ours: praised for viewpoint changes and fewer occlusions, though sometimes unclear with missing instruments
Ours (Mask+Dist): regarded as cleaner and more stable, with added educational value from the surgeon's perspective

Conclusion

- Proposed **Occlusion-free 4D Gaussian Splatting pipeline** for open surgery video synthesis with McSL
- Achieved **higher visual quality** and **better user satisfaction** compared to baseline method
- Future work:
  - Enhance rendering fidelity with prior knowledge (e.g., hand and instrument models)
  - Explore educational use in VR headsets

References

[1] Kato et al., "High-quality virtual single-viewpoint surgical video: Geometric autocalibration of multiple cameras in surgical lights" in MICCAI, 2023.
[2] Ravi et al., "SAM 2: Segment Anything in Images and Videos", in ICLR, 2025.