Self-supervised Learning of Reconstructing Deformable Linear Objects under Single-Frame Occluded View

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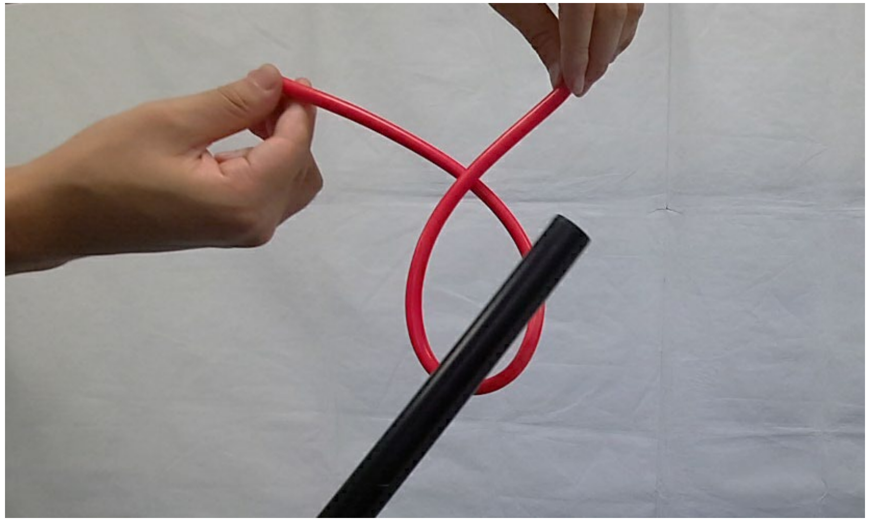
Highlights

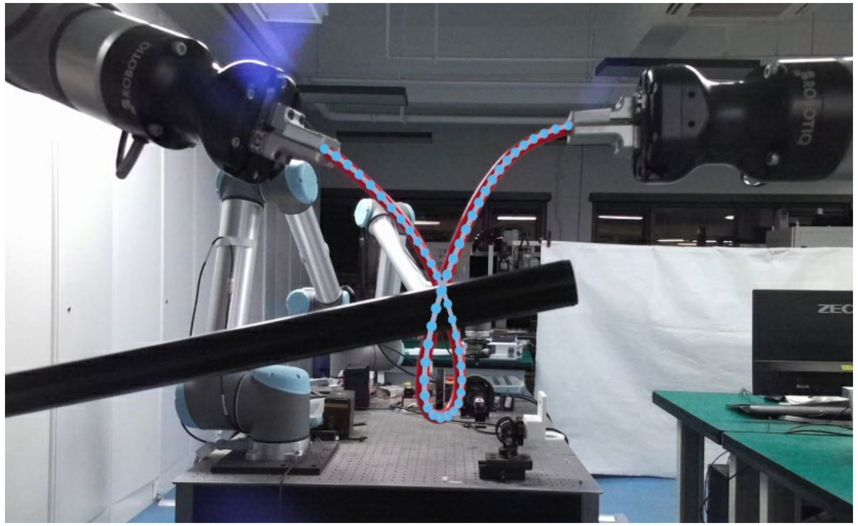
3D efficient self-supervised DLO reconstruction algorithm:

- **Efficient No-Label Training**: Enables data collection in **real-world** settings, even **manually**.
- **Robust 3D State Inference**: Reconstructs DLO from a **single frame**, even with **severe occlusions**.

Training Stage



Inference Stage

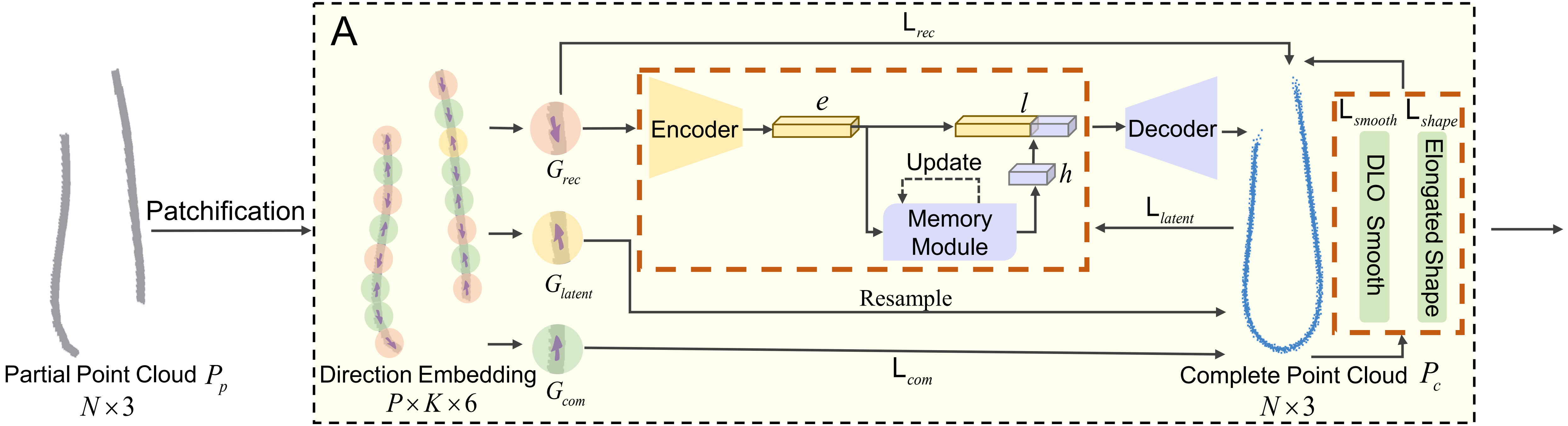


Occluded DLO   Reconstructed Key Points

Framework

Self-supervised DLO occlusion single-frame reconstruction framework:

- A. Self-supervised DLO Point Cloud Completion
- B. Ordered Key Points Generation



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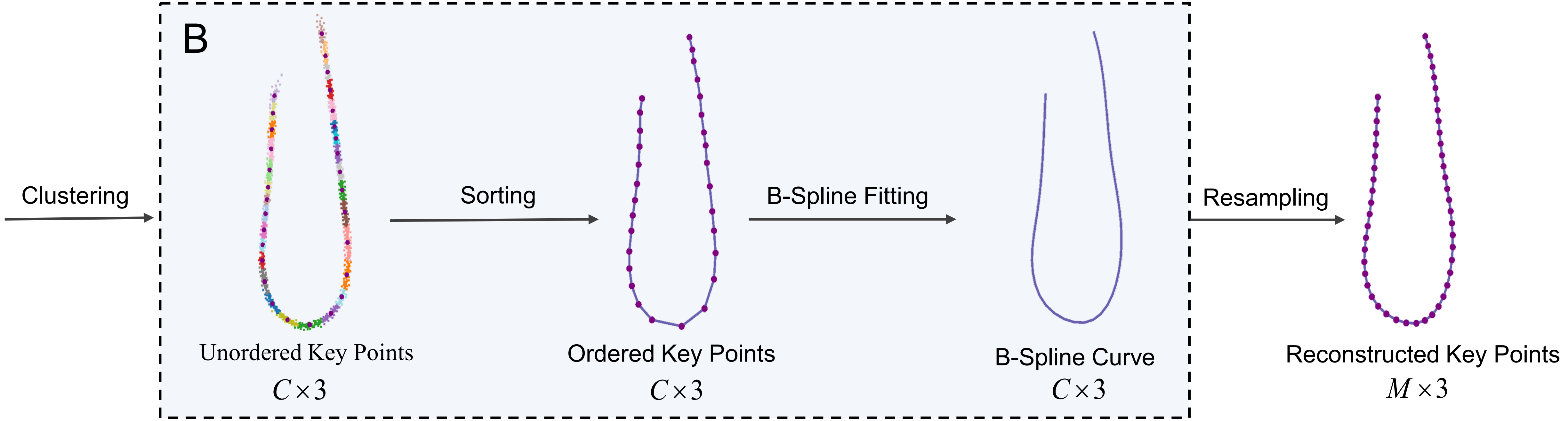
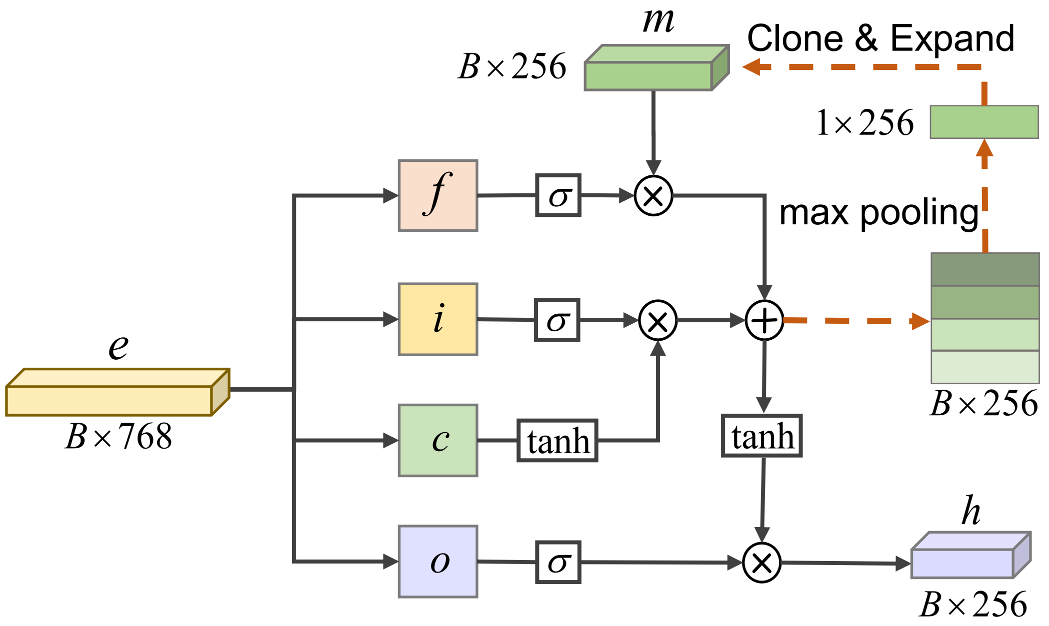


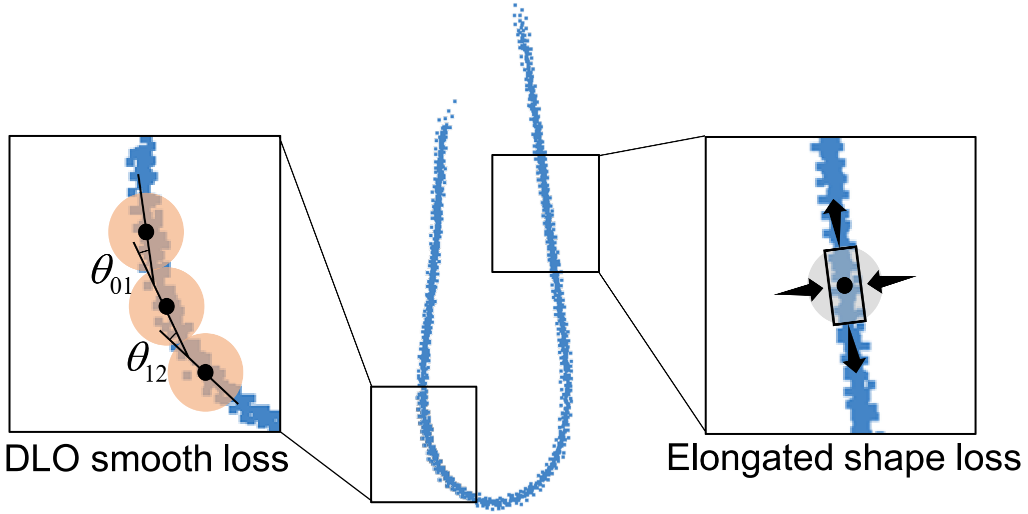
Innovations

Memory module



Extract memory across samples by **max pooling** to reinforce **the supervisory signals**.

DLO shape constraints

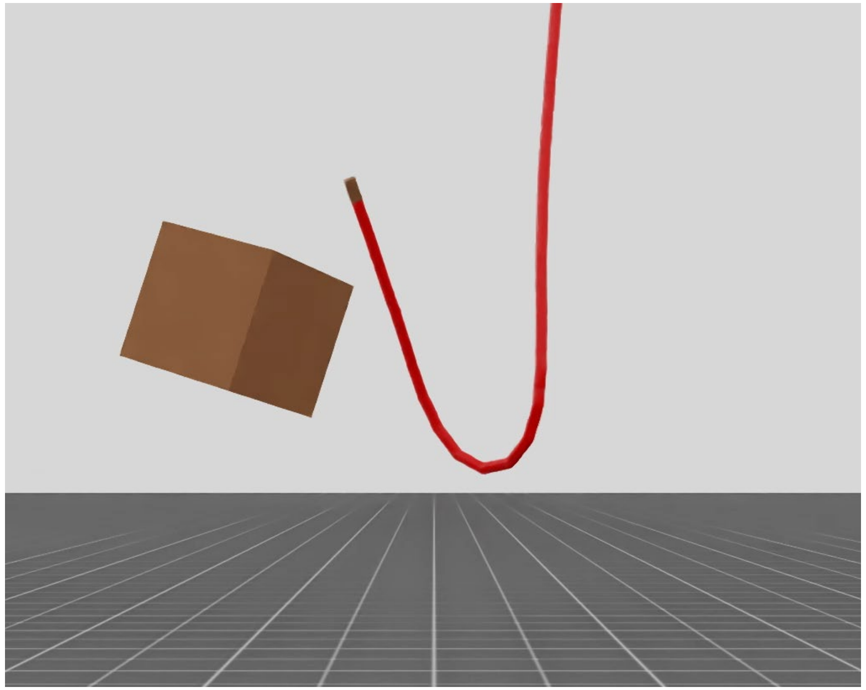


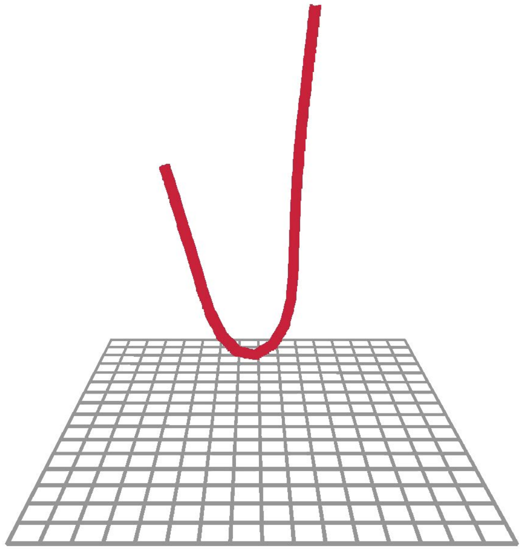
Integrate **DLO priors**, like **smooth and elongated shapes**, to enhance reconstruction performance.

Experiments

Simulation Experiments—Synthetic Dataset Generation

- The DLO has **randomly moving endpoints**, while **an occlusion cube** moves to simulate occlusions.
- **7,000** DLO samples, split into training, validation, and test sets with an approximate **7:2:1** ratio.





Experiments

Simulation Experiments—Results

- Evaluation **metrics comparison** and **ablation study** on synthetic DLO datasets.

ID	Algorithms	Success Rate(%) ↑	D_{1bi}(mm) ↓	D_1(mm) ↓	D_2(mm) ↓	D_3 ↓	D_4 ↓
1	Lv [1]	85	23.92	10.38	23.81	.276	5.20
2	DLOFTBs [2]	95	17.35	7.76	19.54	.085	5.47
3	Sun [3]	87	20.77	7.34	20.09	.065	4.96
4	P2C	100	13.02	6.44	16.17	.028	4.90
	MP2C	100	**12.79**	**6.22**	12.58	.026	4.81
	MP2CDLO	**100**	12.89	6.24	**11.68**	**.025**	**4.66**

- **P2C:** Original P2C[4] in **our framework.**
- **MP2C:** P2C with **our memory module.**
- **MP2CDLO:** MP2C with **our DLO shape constraints.**

[1] K. Lv, M. Yu, Y. Pu, X. Jiang, G. Huang, and X. Li, “Learning to estimate 3-d states of deformable linear objects from single-frame occluded point clouds,” in 2023 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2023, pp. 7119–7125.

[2] P. Kicki, A. Szymko, and K. Walas, “Dloftbs–fast tracking of deformable linear objects with b-splines,” in 2023 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2023, pp. 7104–7110.

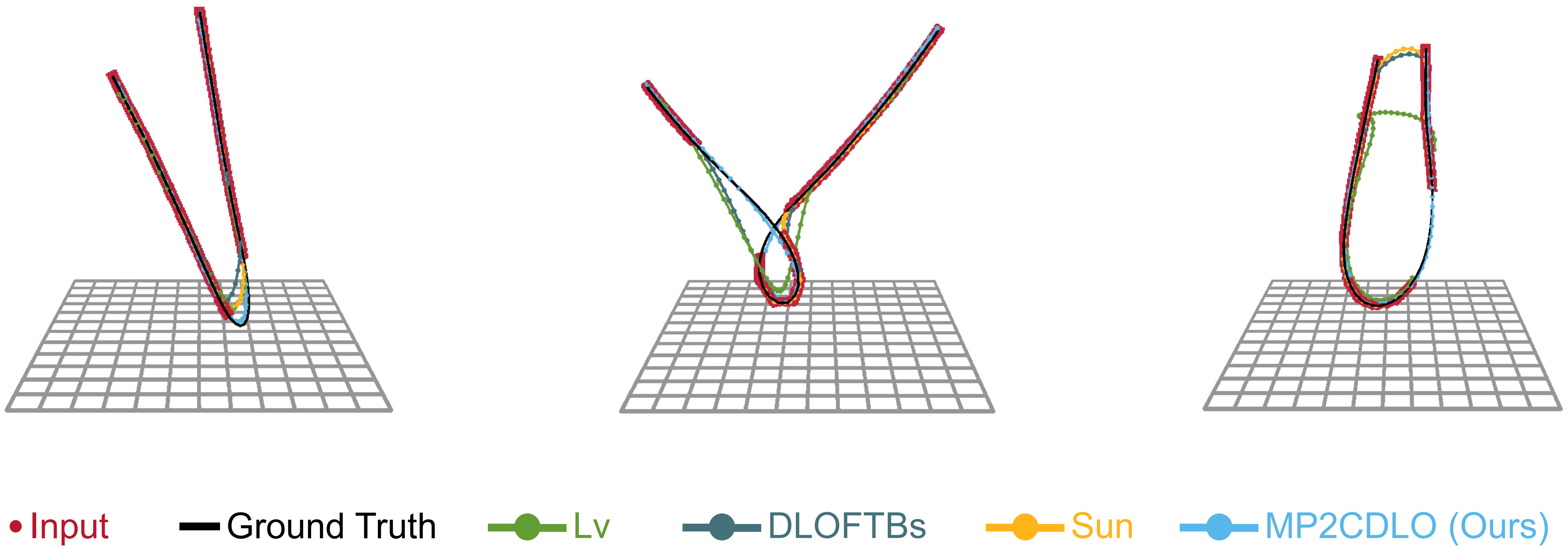
[3] S. Zhaole, H. Zhou, L. Nanbo, L. Chen, J. Zhu, and R. B. Fisher, “A robust deformable linear object perception pipeline in 3d: From segmentation to reconstruction,” IEEE Robotics and Automation Letters, vol. 9, no. 1, pp. 843–850, 2023.

[4] R. Cui, S. Qiu, S. Anwar, J. Liu, C. Xing, J. Zhang, and N. Barnes, “P2c: Self-supervised point cloud completion from single partial clouds,” in Proceedings of the IEEE/CVF International Conference on Computer Vision, 2023, pp. 14 351–14 360.

Experiments

Simulation Experiments—Results

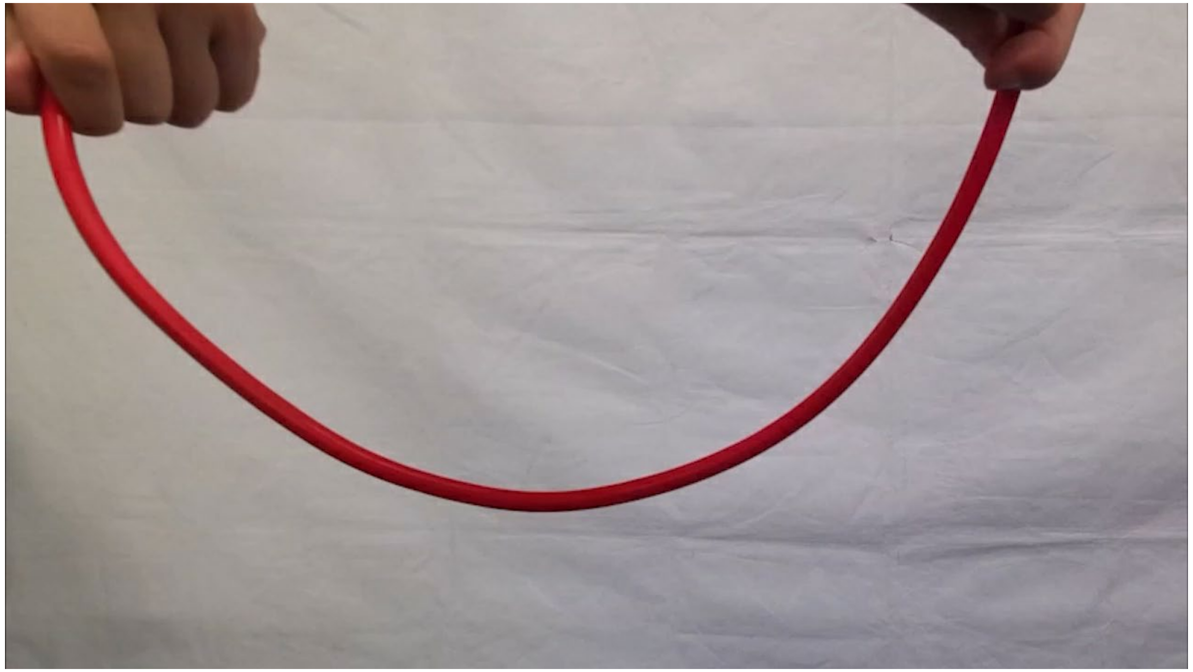
- Reconstruction **visualization comparison** on synthetic DLO datasets.

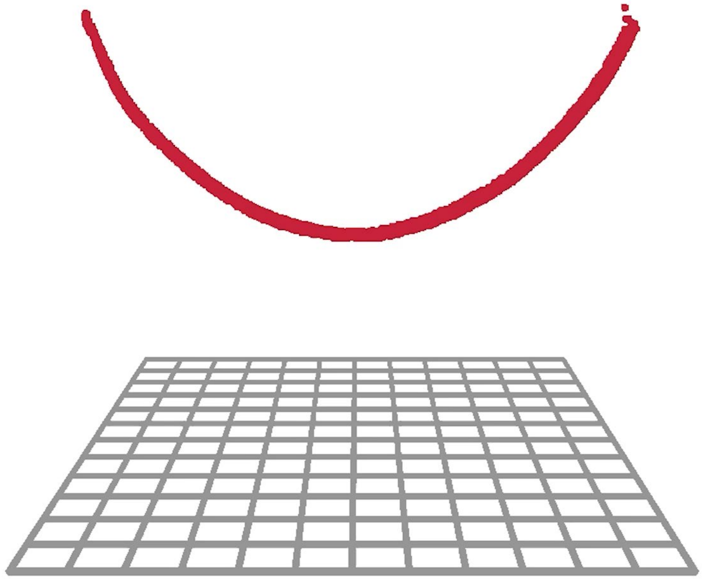


Experiments

Real-world Experiments—Training Stage

- Simplify data collection by **manual manipulation** of both ends of the DLO under an RGB-D camera.

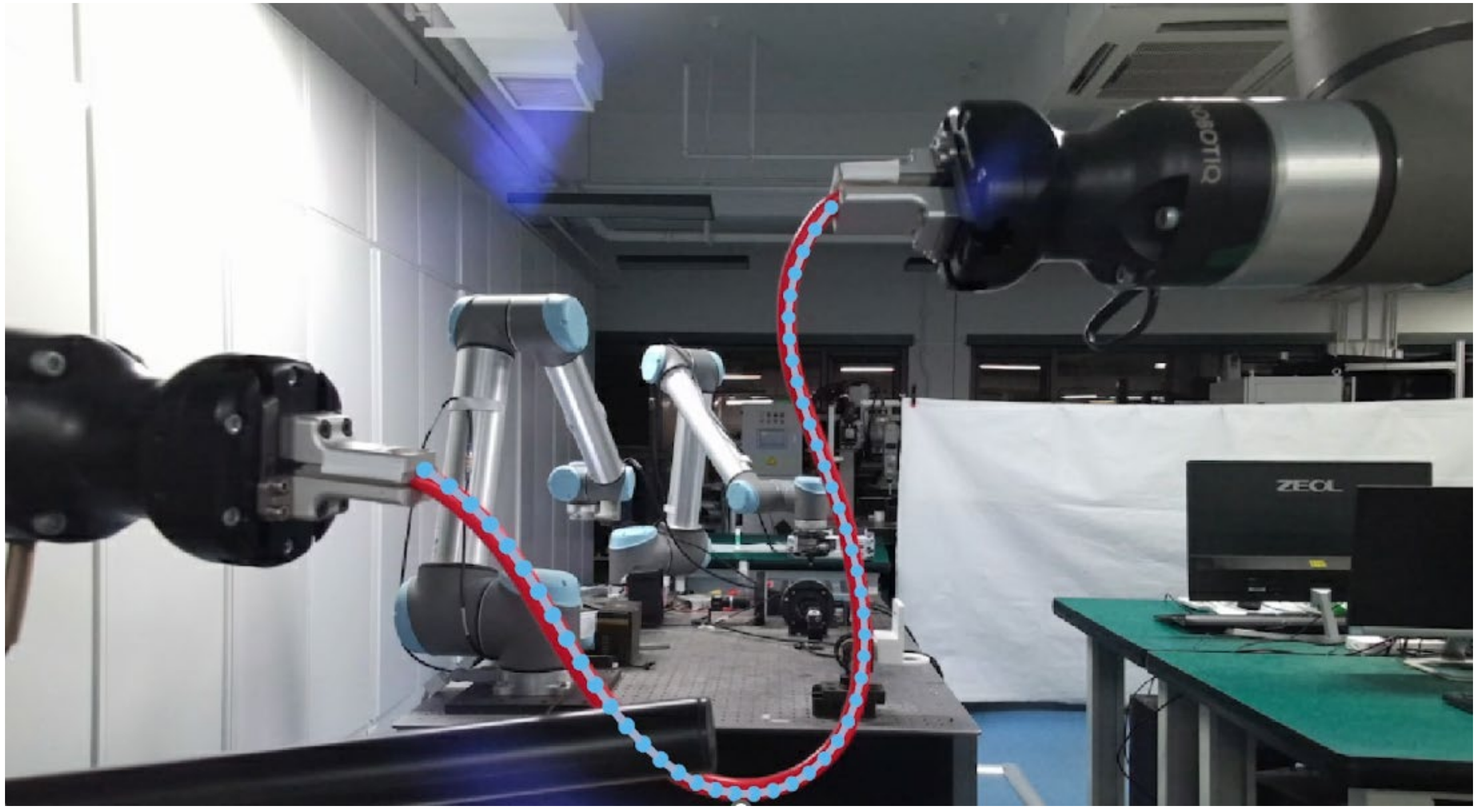


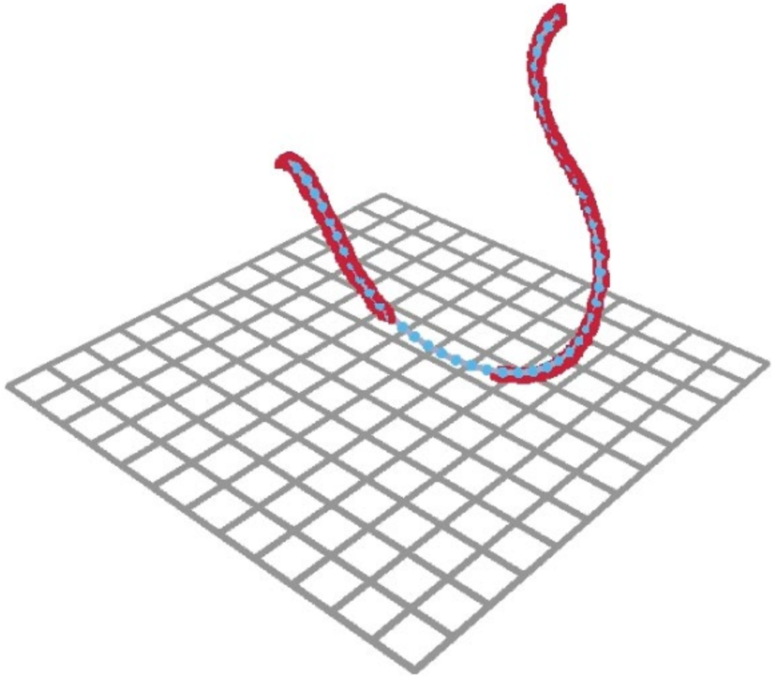


Experiments

Real-world Experiments—Inference Stage

- **Normal Scenario**: Occasional occlusions occur when two arms manipulate the DLO.

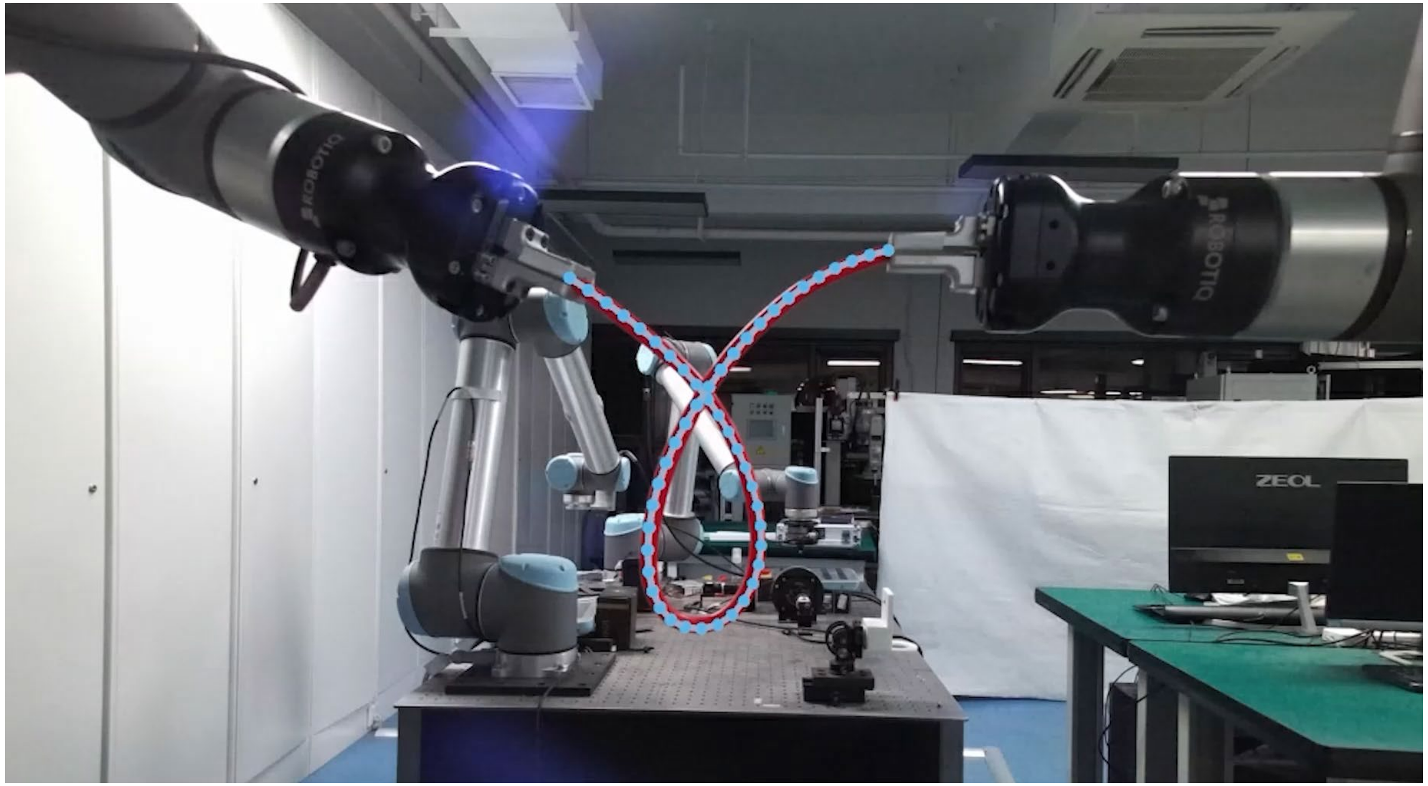




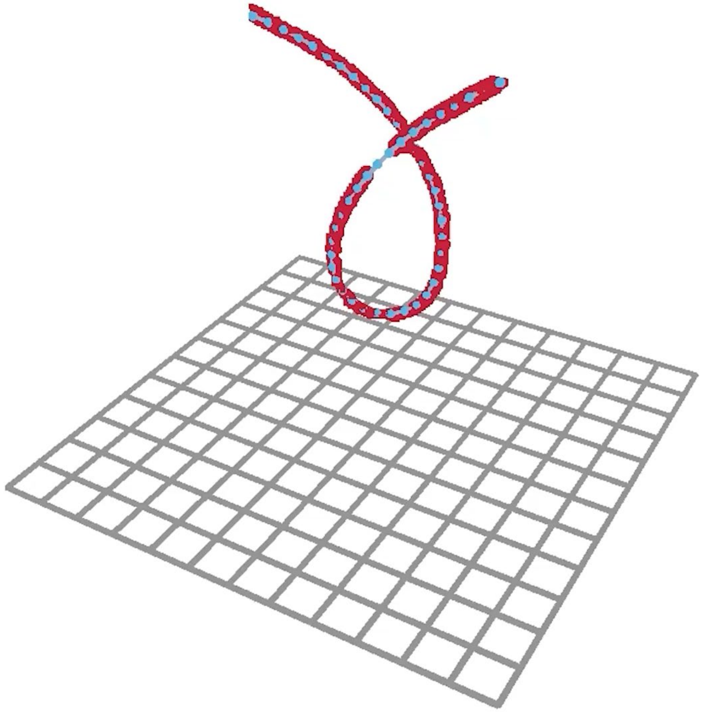
Experiments

Real-world Experiments—Inference Stage

- **Complex Scenario**: Both occlusions and various self-intersections may occur simultaneously.



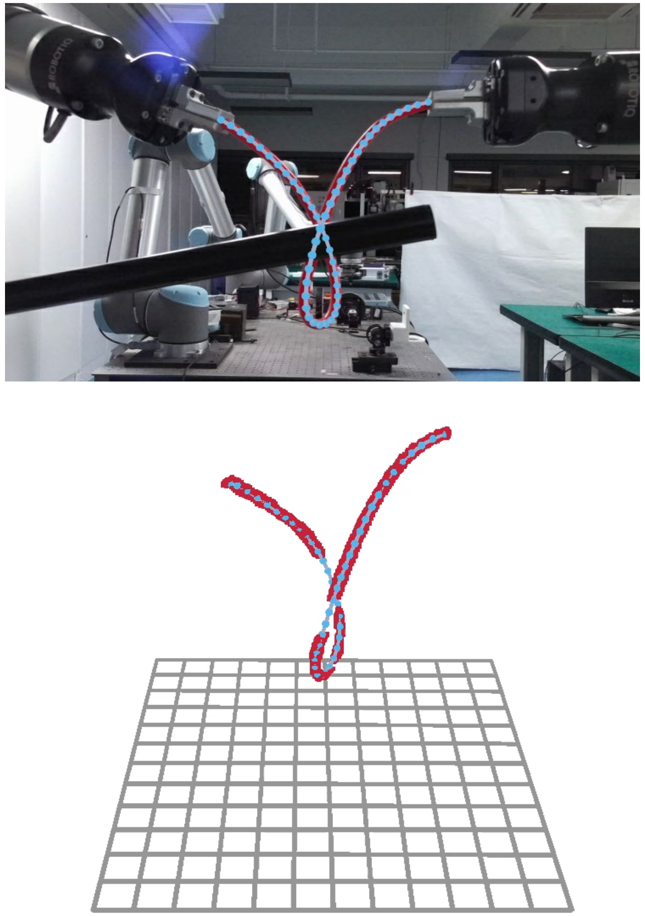
Speed ×1.5



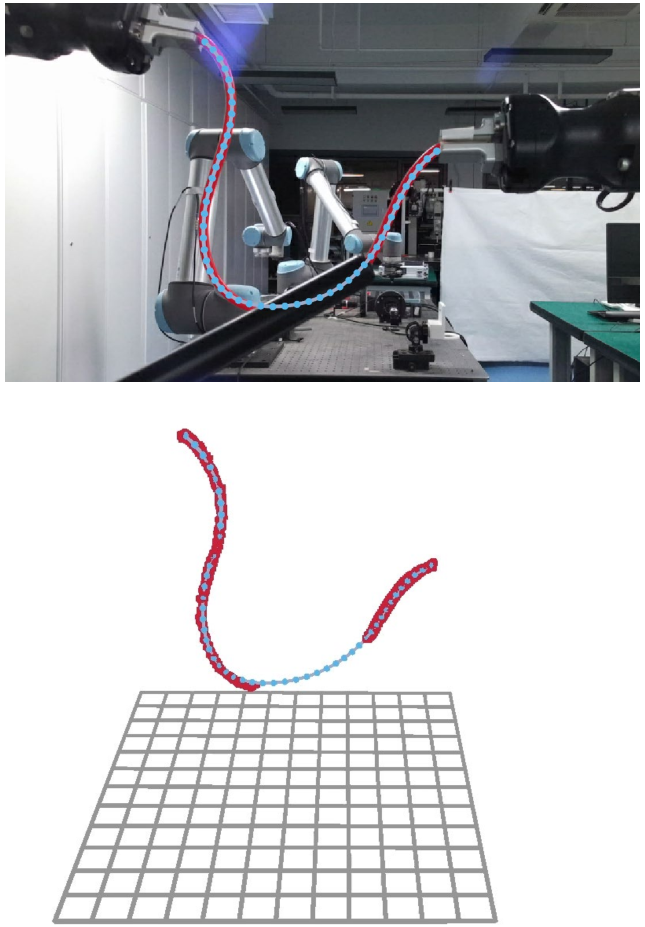
Experiments

Real-world Experiments—Inference Cases

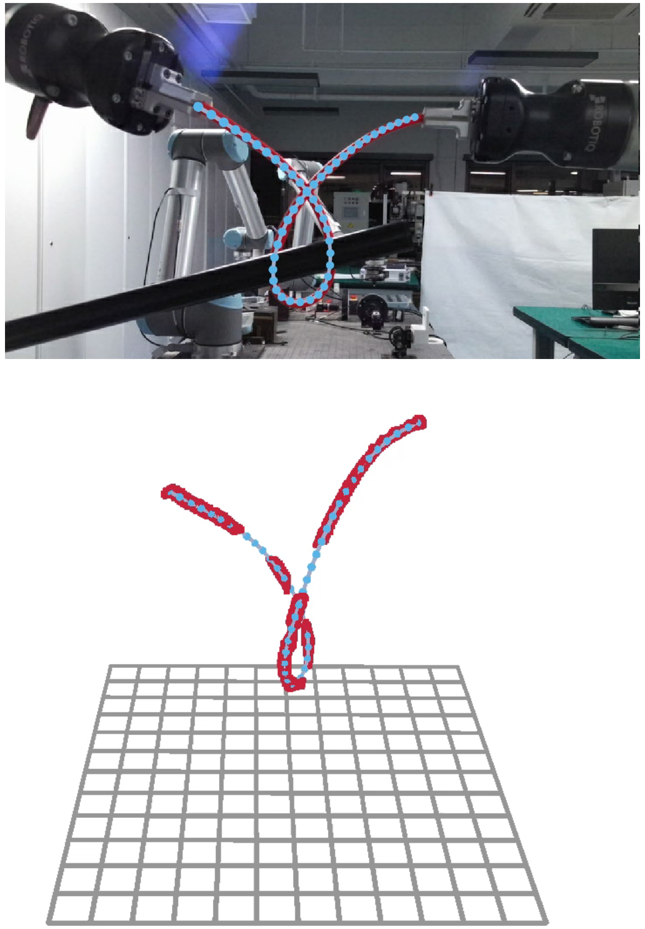
Viewpoint Occlusion Self-intersection



Extensive Occlusion

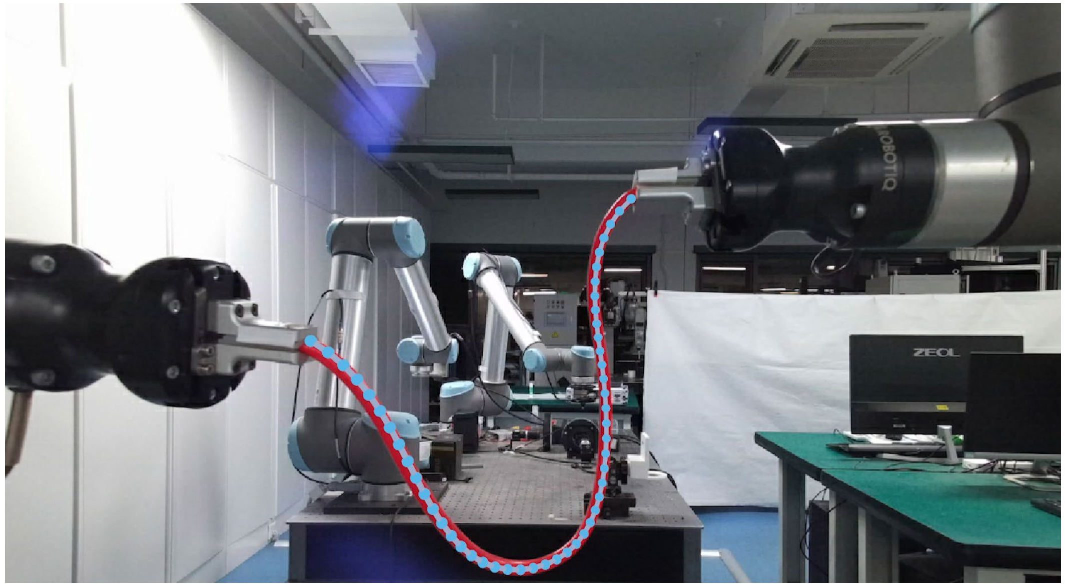


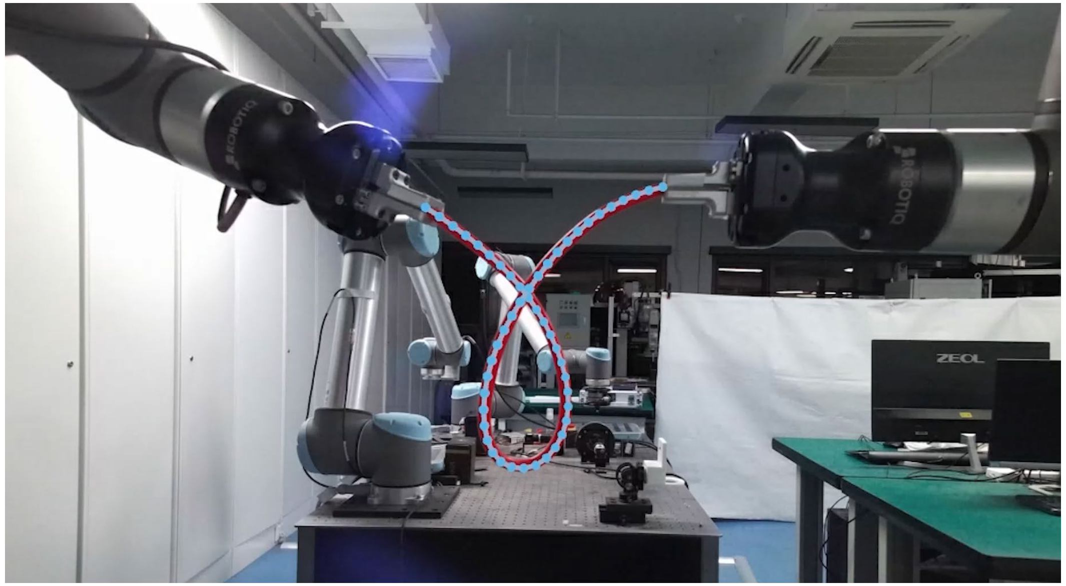
Spatial Proximity Self-intersection



Contributions

- **Self-supervised Reconstruction Framework：** **Efficiently** reconstructs DLO from partial point clouds.
- **Memory Module：** Enhances completion by **consolidating prototype** information **across samples**.
- **DLO Shape Constraints：** Leverages **structural priors** for better DLO representations.





Thank you !

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For more details, please refer to our project website: https://mp2cdlo.github.io/MP2CDLO/