Simultaneous Shape Tracking of Multiple Deformable Linear Objects with Global-Local Topology Preservation

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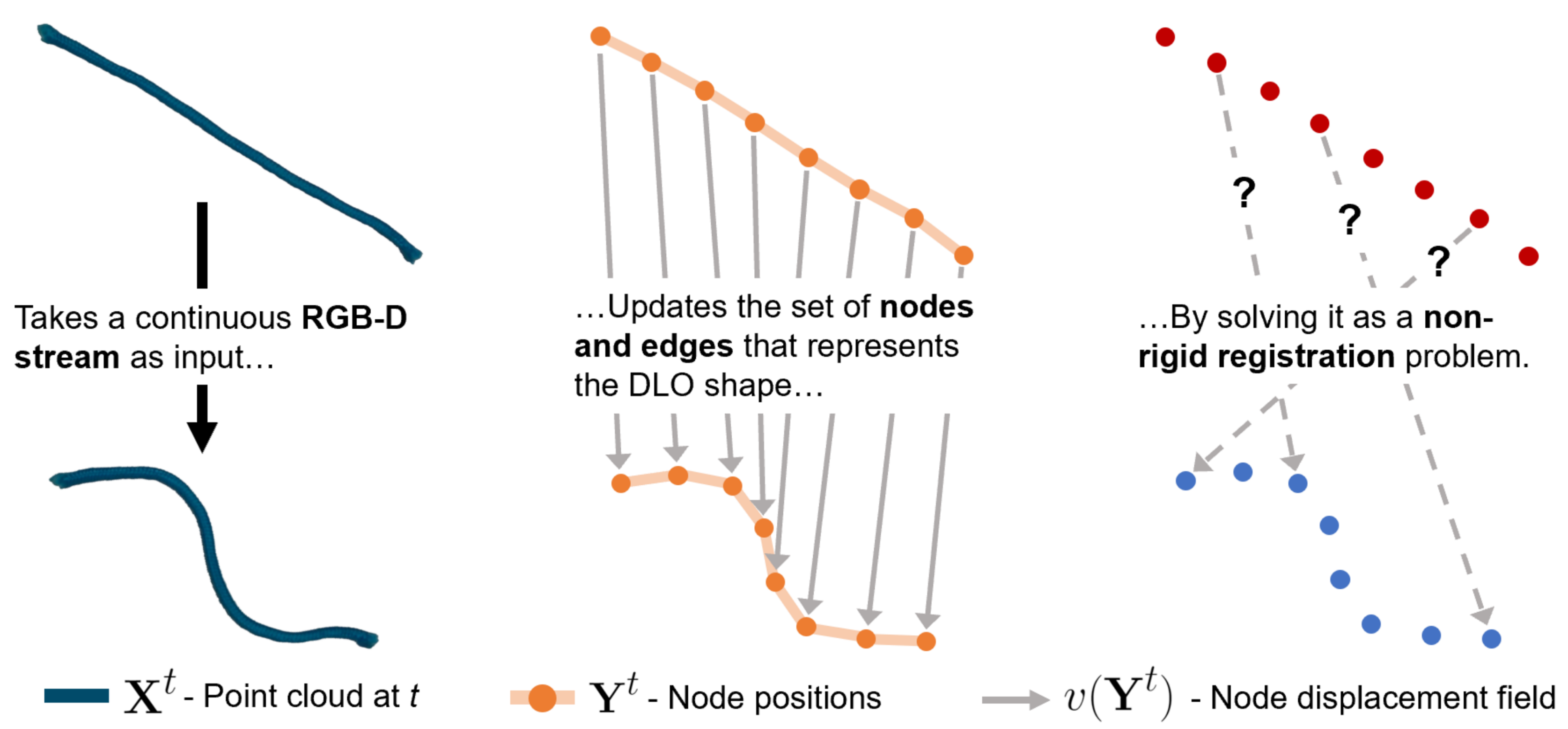
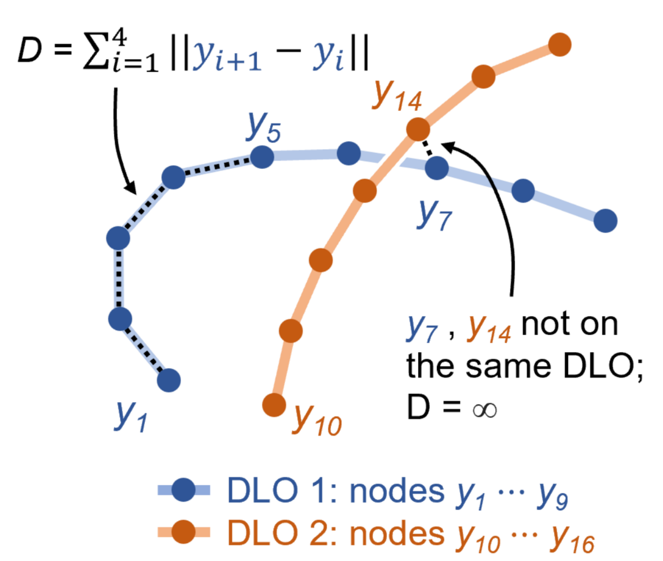
Introduction

This work presents an algorithm for tracking the shape of multiple entangling Deformable Linear Objects (DLOs) from a sequence of RGB-D images. This algorithm runs in real-time and improves on the single-DLO Global Local Topology Perservation (GLTP) tracking approach by tracking multiple objects. This is achieved by performing instance segmentation (expensive) on the first frame for initialization and performing semantic segmentation (cheap) on subsequent frames.



Theoretical Background

Using the geodesic distance metric shown on the right, the distance between two nodes on the same DLO is set to the sum of the segment lengths between them. If the two nodes are not on the same DLO, the distance between them is set to infinity.

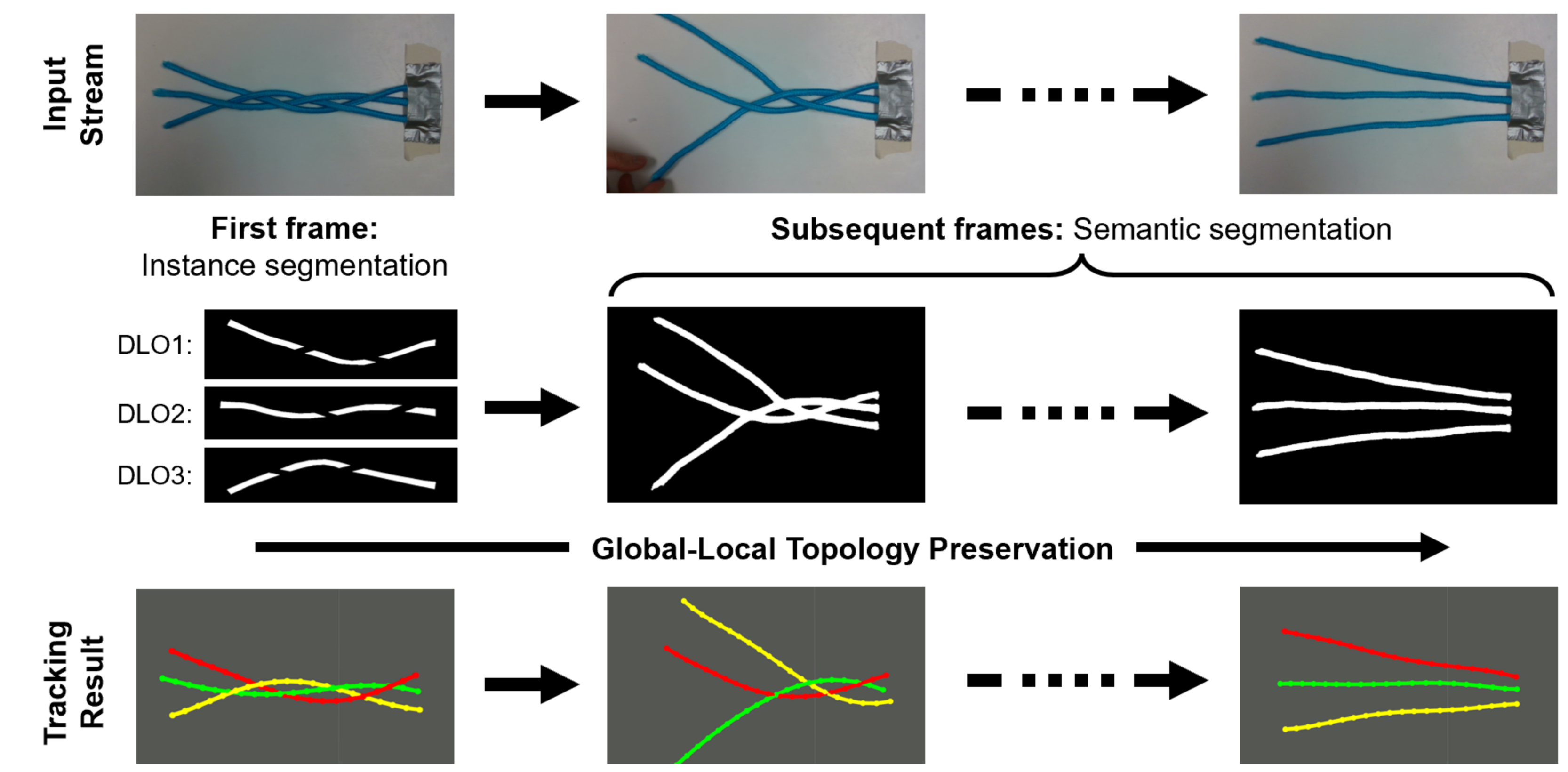


The total cost of GLTP is the sum of the cost of Gaussian Mixture Model Clustering (GMM), the cost of Motion Coherence Theory (MCT), and the cost of Locally Linear Embedding (LLE). The total cost shown below is updated iteratively using the Expectation-Maximization algorithm.

$$E(v(\mathbf{z}), \sigma^2) = E_{\text{GMM}} + E_{\text{MCT}} + E_{\text{LLE}}$$
$$= \sum_{n=1}^{N} \sum_{m=1}^{M} \frac{1}{2\sigma^2} p(m|\mathbf{x}_n^t) \|\mathbf{x}_n^t - \mathbf{y}_m^t\|^2 + \frac{3N_p}{2} \log(\sigma^2)$$
$$+ \frac{\lambda}{2} \int_{\mathbb{R}^3} |\tilde{v}(\mathbf{s})|^2 / \tilde{G}(\|\mathbf{s}\|) d\mathbf{s} + \sum_{m=1}^{M} \|\mathbf{y}_m^t - \sum_{i=m-Q}^{m+Q} \mathbf{L}(m,i) \mathbf{y}_i^t\|^2$$

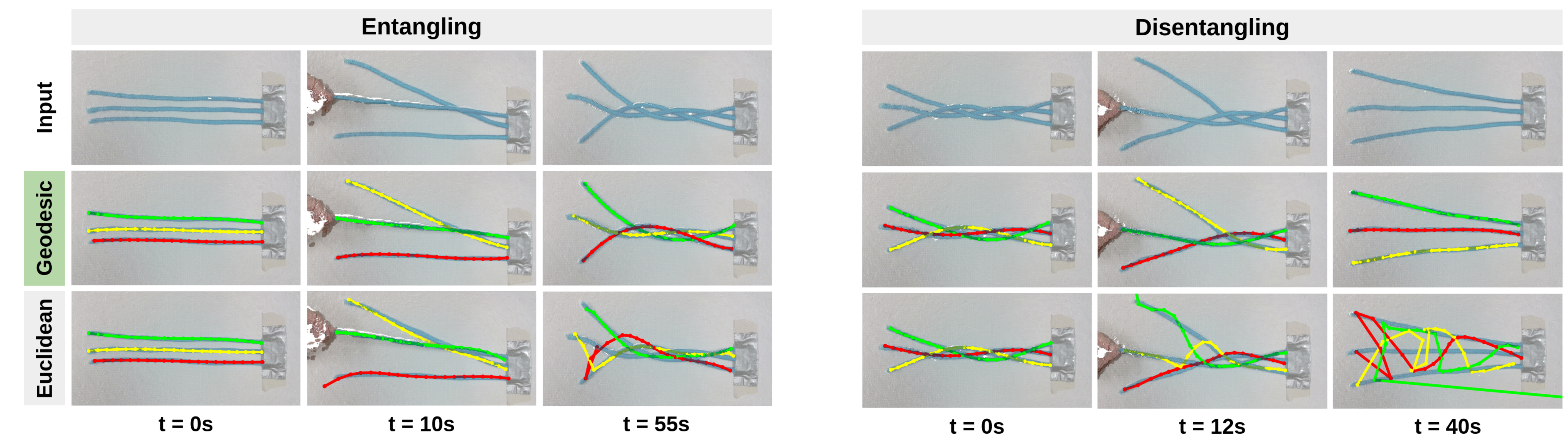
Algorithm

Given a RGB-D stream of multiple entangling DLOs, the algorithm performs instance segmentation on the first frame to initialize a set of nodes and edges for each object in the frame. This step is performed manually due to the limitations of existing instance segmentation algorithms. After initialization, all objects are treated as one object. The GLTP non-rigid point set registration algorithm is used to track all objects together. Only semantic segmentation is required for subsequent frames, which can be easily obtained through color thresholding.



Results

Tracking results (DLO1, DLO2, and DLO3) overlaid on the input point cloud.

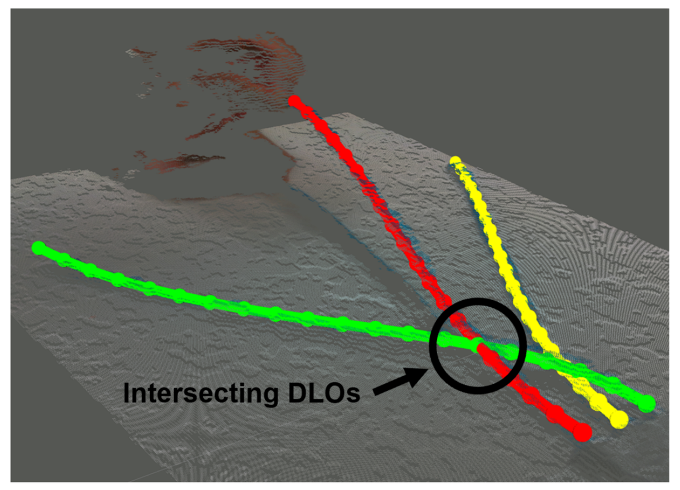


Conclusions

This work presents an algorithm for tracking the shape of multiple entangling DLOs from a sequence of RGB-D images which runs in real time. The algorithm is demonstrated through tracking three entangling and disentangling ropes. The algorithm could be used for tether or power line tracking for mobile robots or in robotic manipulation applications.

Limitations

This algorithm does not resolve the crossing point of intersecting DLOs. Potential solutions include adding physics simulations or a self-intersection constraint for post processing.



References

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Acknowledgments

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https://www.github.com/RMDLO/multi-dlo