TrackDLO: Tracking Deformable Linear Objects Under Occlusion with Motion Coherence

Jingyi Xiang[1], Holly Dinkel[1,3], Harry Zhao[2], Naixiang Gao[1], Brian Coltin[3], Trey Smith[3], Timothy Bretl[1]

[1] University of Illinois at Urbana-Champaign, Urbana, IL, USA [2] Stanford University, Stanford, CA, USA [3] NASA Ames Research Center, Moffett Field, CA, USA

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Introduction

TrackDLO is an algorithm for real-time, vision-only, accurate tracking of deformable linear objects (DLO), including rope, wire and string. TrackDLO was developed to solve the **DLO tracking under occlusion** problem without using physics simulation, contact, or fiducials markers.

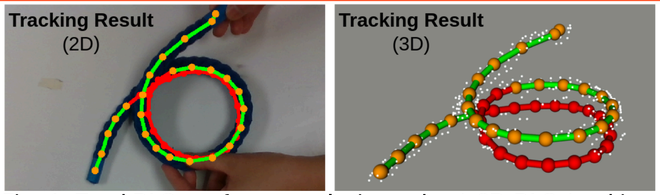


Fig. 1. TrackDLO performs occlusion-robust 3D DLO tracking. (Red) occluded nodes (Orange) visible nodes.

The TrackDLO Algorithm

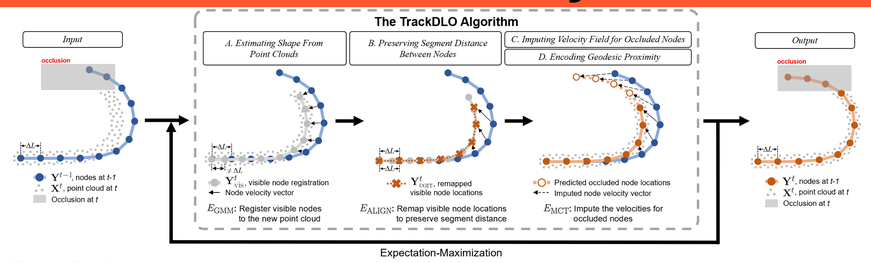


Fig. 2. TrackDLO registers visible nodes to a point cloud, preserves segment distance between nodes, imputes the velocity field for occluded nodes, and encodes geometric proximity.

Preserving Segment Distance

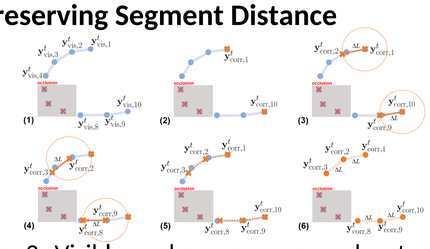


Fig. 3. Visible nodes are remapped onto the piecewise linear curve connecting the registered visible nodes to preserve length.

Estimating Visibility

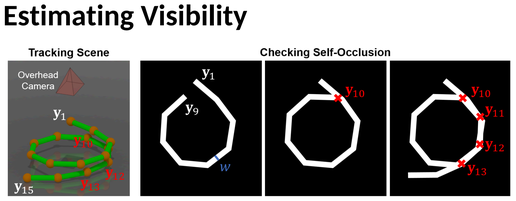


Fig. 4. Each node and edge is projected onto a mask in order of its distance to the camera. If a node projects onto an existing edge, it is considered occluded.

Imputing Velocity Field for Occluded Nodes

Motion Coherence Theory (MCT) suggests features close in proximity should move in similar directions and speeds, ensuring the spatial velocity field is as smooth as possible. The motion of the visible portion of the DLO is used to impute the motion of the occluded portion using MCT.

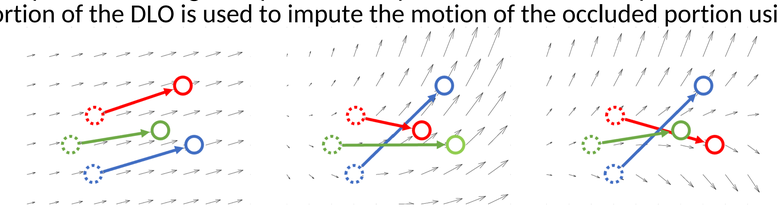


Fig. 5. For the three velocity fields with different levels of smoothness, the leftmost field is the smoothest and most likely to occur.

Encoding Geodesic Proximity

The effect of motion coherence largely depends on how the "closeness" between features is defined. A common choice of distance metric is the Euclidean distance, which is the shortest distance between two features. This metric poorly represents the topology of the DLO. TrackDLO uses the geodesic distance, which measures the distance between two features on the surface of the object.

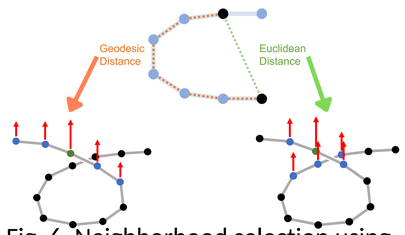
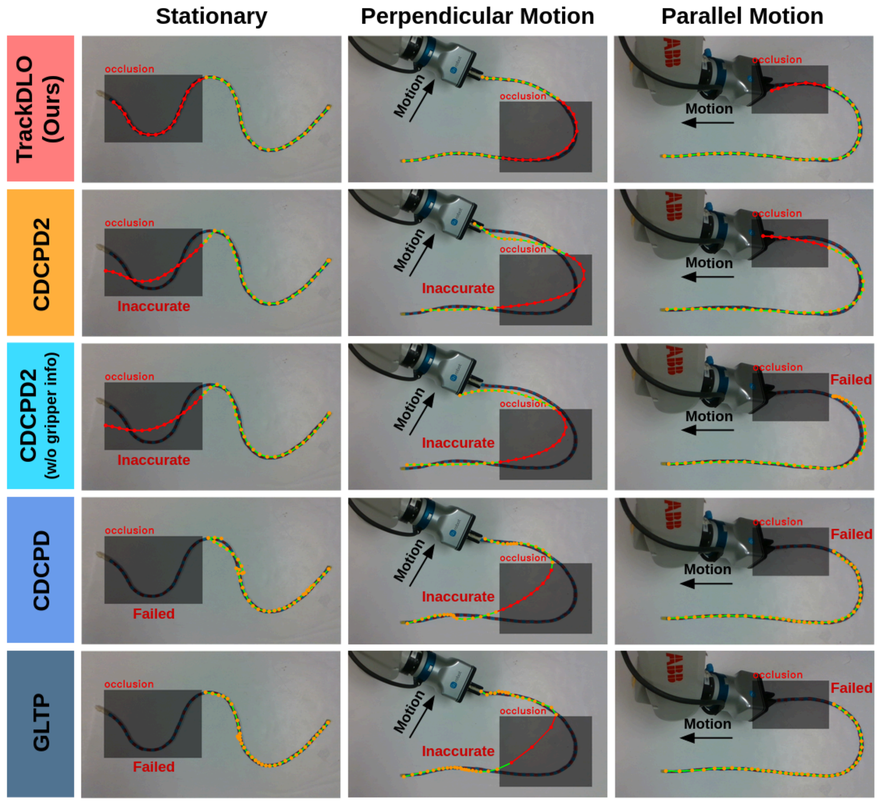


Fig. 6. Neighborhood selection using geodesic and Euclidean distances.

Experiments and Results

Experiment 1: Comparison with Existing Approaches



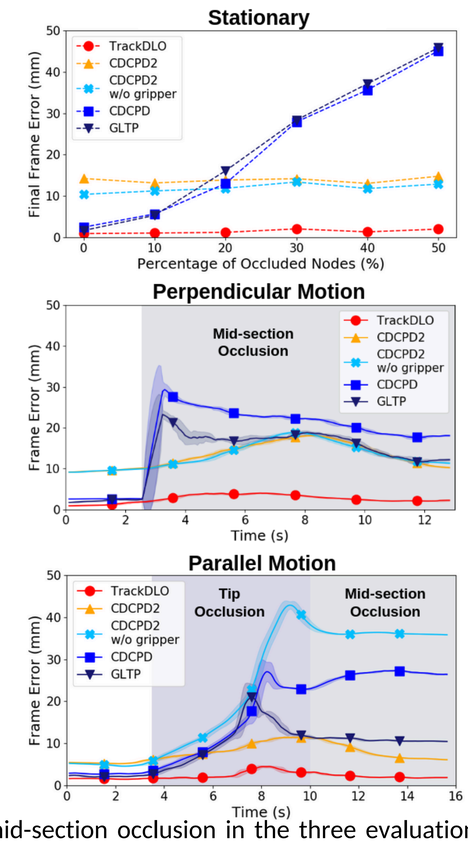


Fig. 7. TrackDLO accurately estimates the state of the DLO under scaled, tip, and mid-section occlusion in the three evaluation scenarios as compared to CDCPD2 with and without gripper information, CDCPD, and GLTP. Among the algorithms evaluated, TrackDLO had the lowest frame error in each scenario.

Experiment 2: Tracking Self-Occluding DLO

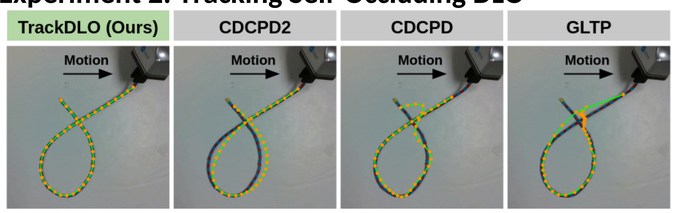


Fig. 8. Through the use of geodesic distance, TrackDLO shows comparable performance to CDCPD2 for tracking a self-occluding rope. The CDCPD and GLTP algorithms use Euclidean distance and fail to resolve the occlusion.

Experiment 3: Distance Metric and Motion Coherence

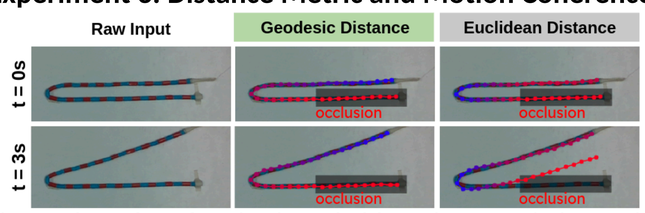


Fig. 9. The color of nodes is scaled based on proximity to the nearest occluded node from red (close) to blue (far). Using Euclidean distance, the top part is mostly red indicating close proximity to occluded nodes. When the top part moves, the bottom part also moves even though it should be stationary.

Conclusions and Future Research

TrackDLO is a real-time, accurate algorithm for tracking occluded Deformable Linear Objects. Experiments and supplementary material demonstrate the robustness of TrackDLO under tip, midsection, and self-occlusion for a rope and latex tubing.
Future work could integrate instance segmentation with tracking for shape estimation of multiple moving DLOs.

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