TrackDLO: Tracking Deformable Linear Objects Under Occlusion with Motion Coherence

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Introduction

We present TrackDLO, an algorithm for real-time, accurate tracking of deformable linear object (DLO) (e.g., rope, wire, string) shapes. This algorithm tracks DLOs in RGB-D imagery, for use in manipulation tasks such as knot tying or wire routing, or to monitor DLOs for collision prevention. These canonical tasks are common in applications like robotic surgery, industrial automation, power line avoidance and human habitat maintenance. More specifically, we are interested in solving the **DLO tracking under occlusion** problem.

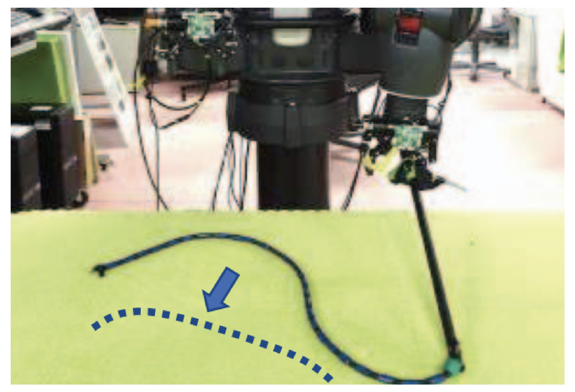


Fig 1. Robotic manipulation of DLO.

Methods

The Motion Coherence Theory

The Motion Coherence Theory suggests that features close to each other in space should move in similar directions and speeds. In other words, the *spatial* velocity field of the moving object should be as smooth as possible. In the velocity fields shown below, the first one shows the most smoothness, hence is the most possible to occur. Given the motion of the visible portion of the DLO, we use the Motion Coherence Theory to impute the motion of the occluded portion.

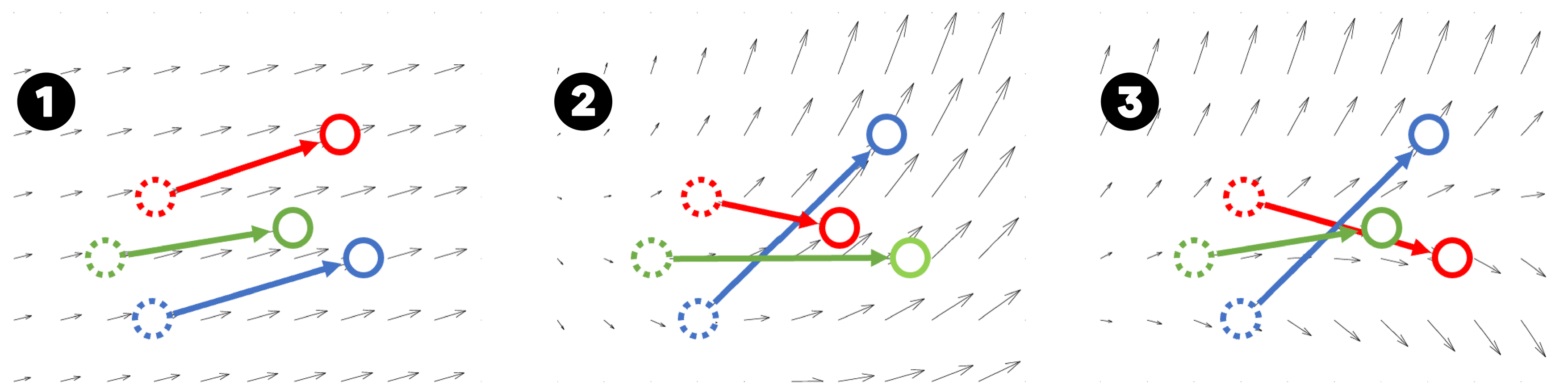


Fig ?. Velocity fields with different levels of smoothness.

Geodesic vs. Euclidean Distance

- 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 simply the shortest distance between two features. However, this metric poorly represents the geometry of the DLO.
- We utilize the geodesic distance, which measures the distance between two features *on the surface* of the object.

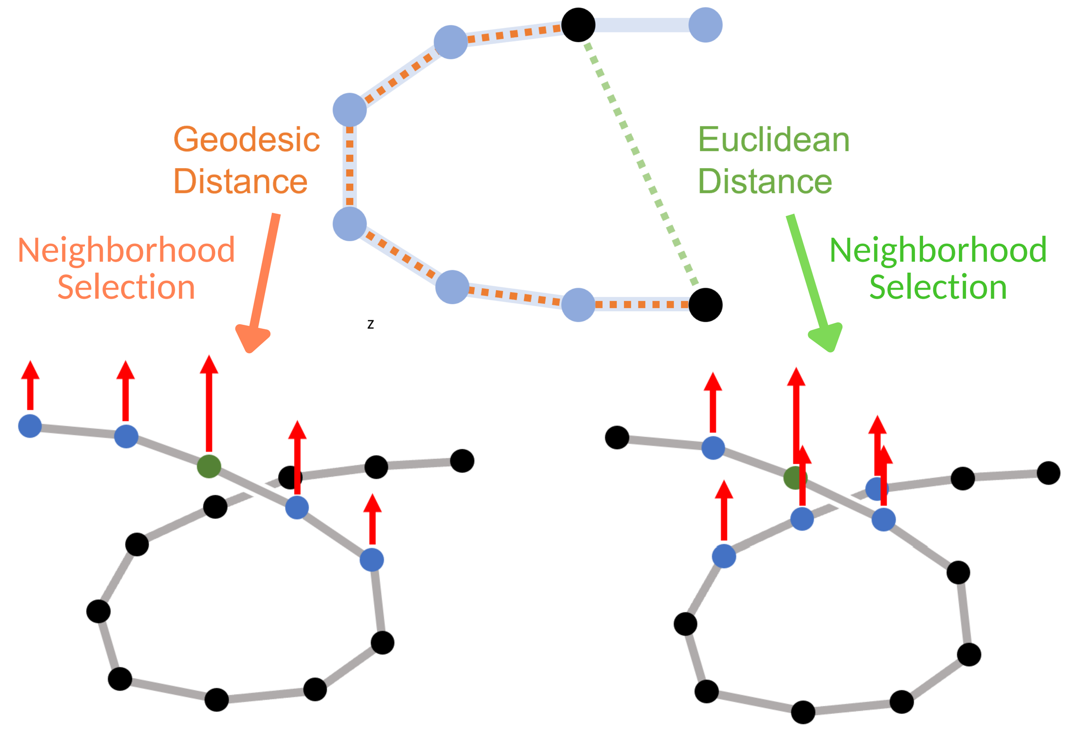


Fig 2. Neighborhood selection based on geodesic and Euclidean distances.

Conclusions and Future Research

We introduced TrackDLO, a real-time, accurate algorithm for tracking occluded Deformable Linear Objects. We showed the robustness of TrackDLO under three types of occlusion for a rope. Future work could integrate instance segmentation with tracking for accurate shape estimation of multiple DLOs as they move in cluttered environments.

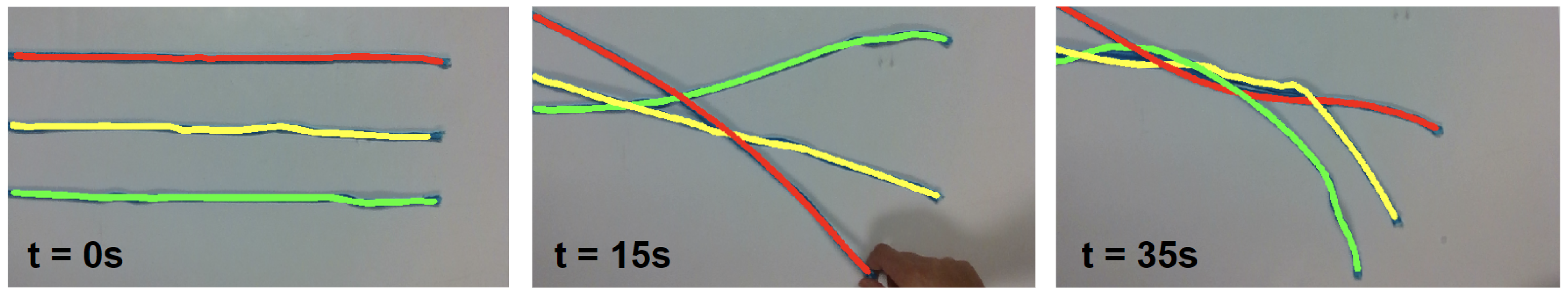


Fig 6. Multi-DLO tracking preliminary results.

Experiment Results

Experiment 1: Tracking Self-Intersecting DLO

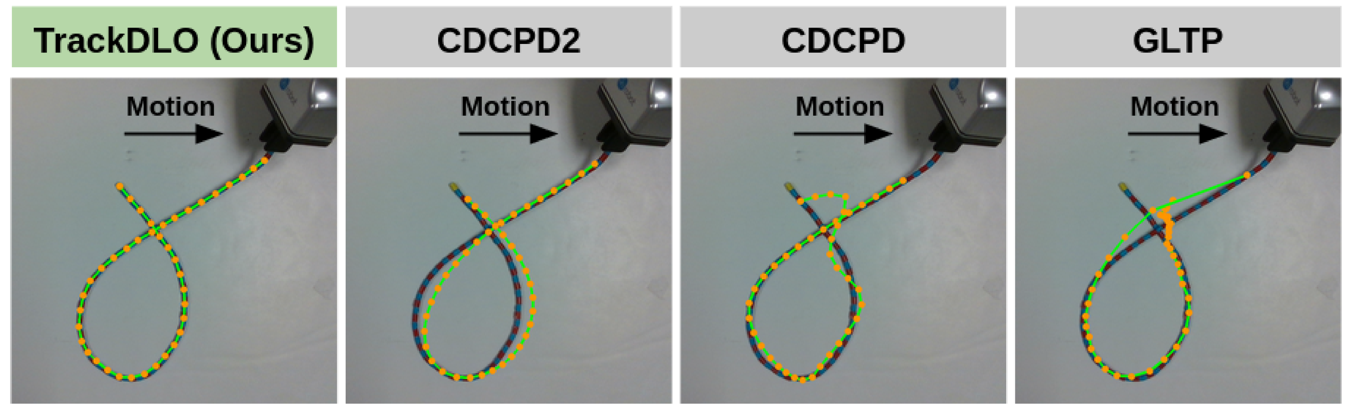


Fig. 3. Through the use of geodesic distance, TrackDLO shows comparable performance to the CDCPD2, the current state-of-the-art, for tracking a self-intersecting rope. The CDCPD and GLTP algorithms, which both use Euclidean distance, fail to track the correct shape of the DLO in this scenario.

Experiment 2: Distance Metric and Motion Coherence

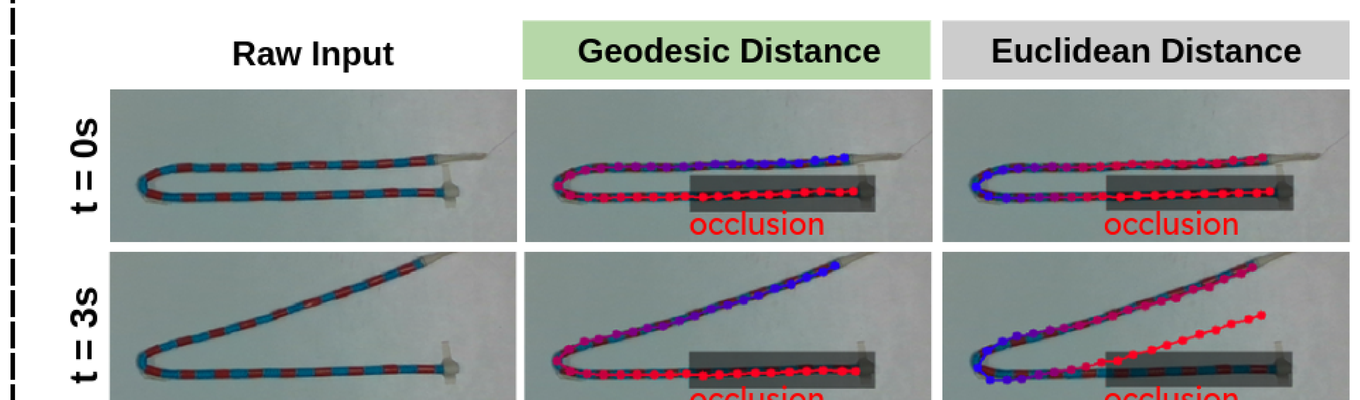
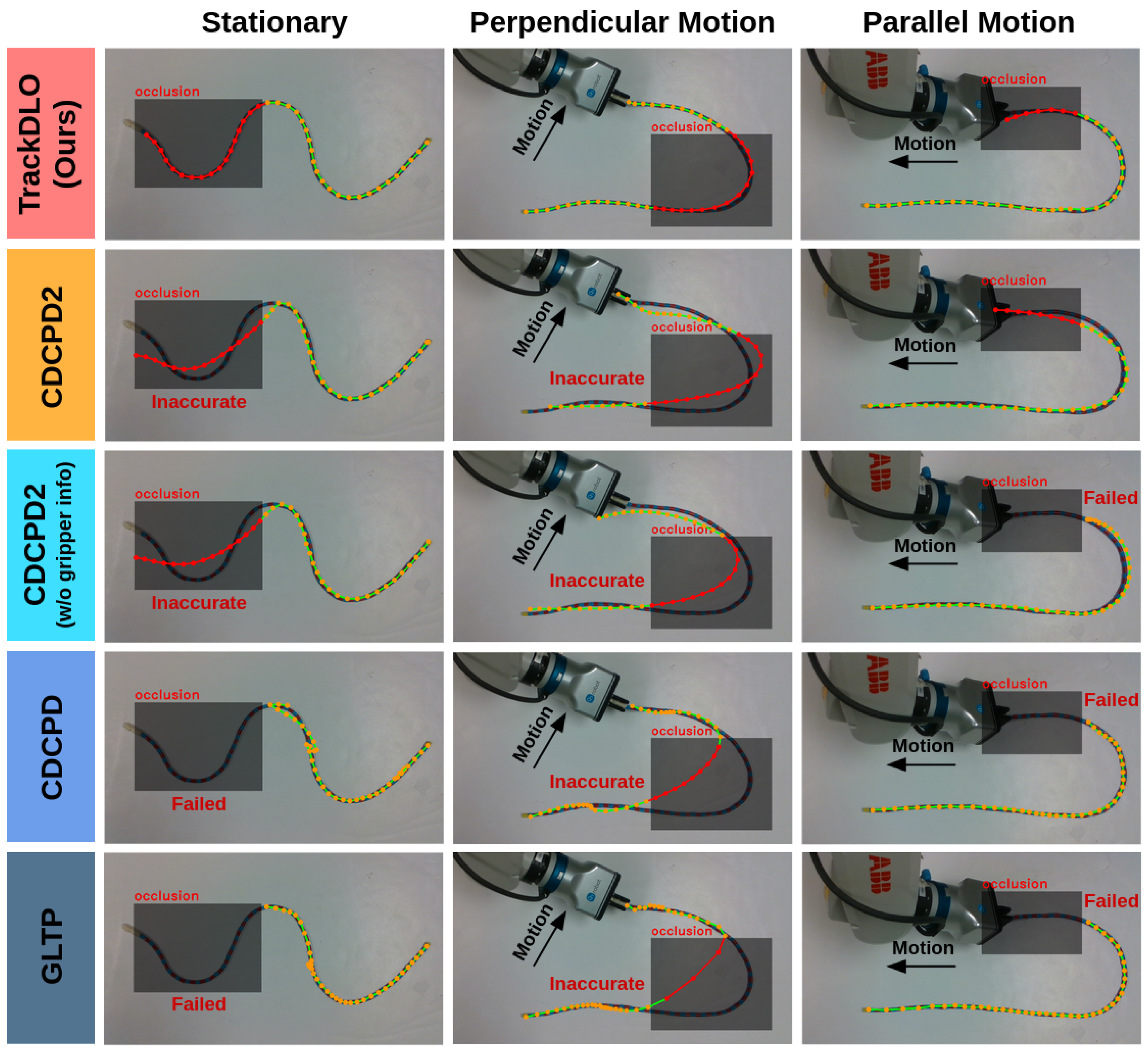


Fig. 4. The color of nodes is scaled based on proximity to the nearest occluded node from red (close) to blue (far). Using Euclidean distance, the top part is mostly red indicating close proximity to occluded nodes. When the top part moves, the bottom part also moves even though it should be stationary.

Experiment 3: Comparison with Existing Approaches



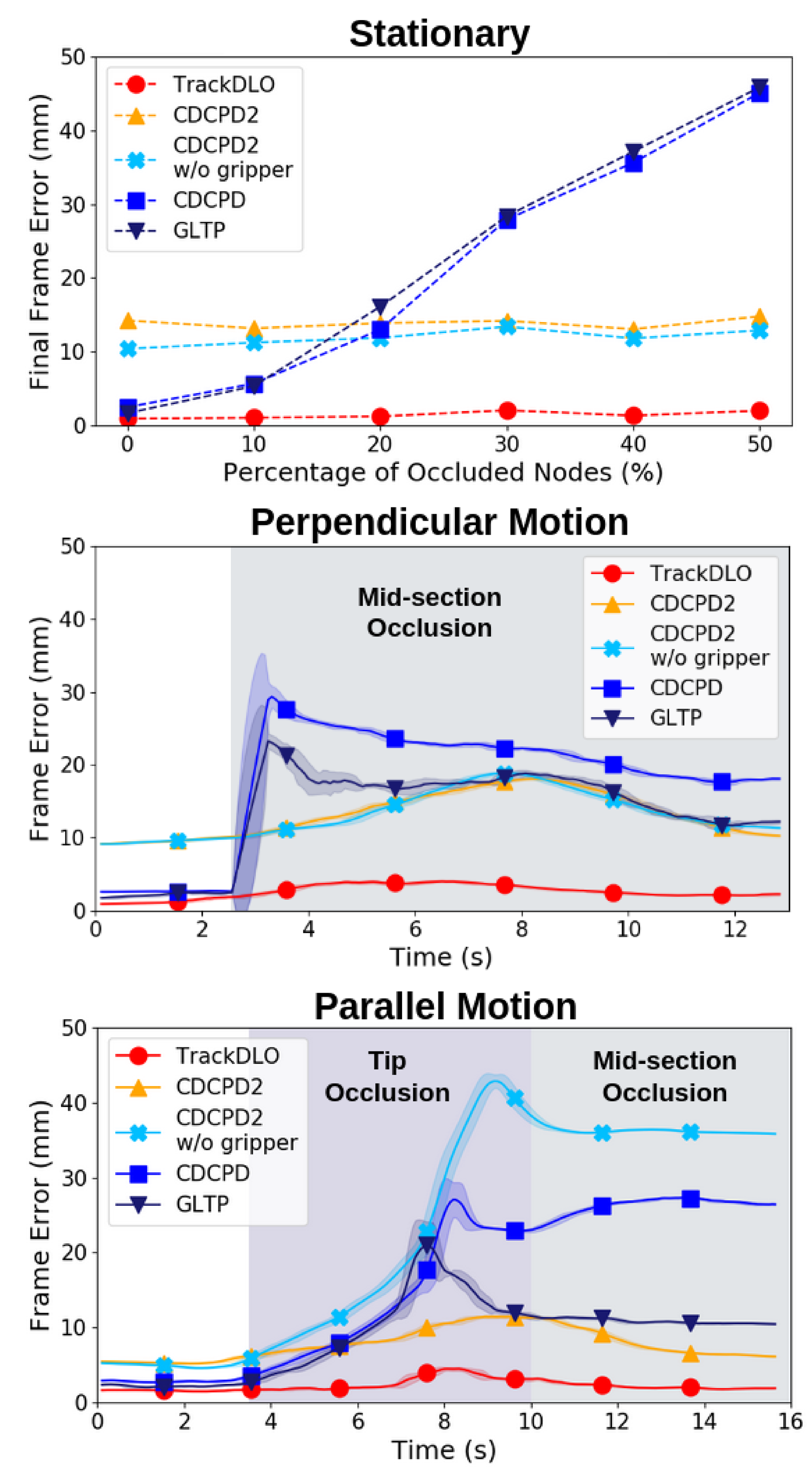


Fig. 5. TrackDLO accurately estimates the state of the DLO under scaled, tip, and mid-section occlusion in the three evaluation scenarios as compared to CDCPD2 with and without gripper information, CDCPD, and GLTP. Among the algorithms evaluated, TrackDLO had the lowest frame error in each scenario.

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