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Estimating the Kinematic State of a Lockbox Puzzle

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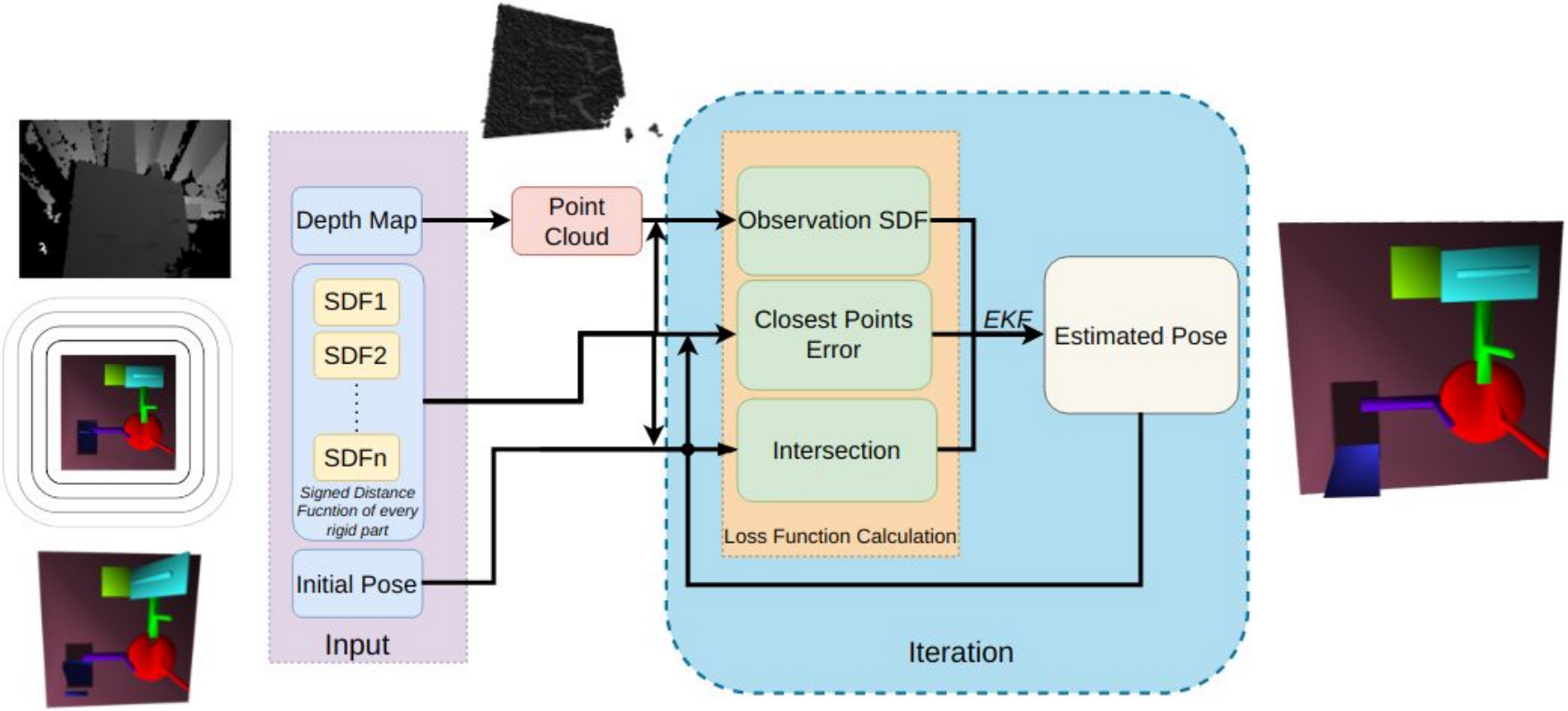
Motivation: Understand the articulated objects

Framework


Depth Map
Point Cloud
SDF1
SDF2
SDFn
Signed Distance Fucntion of every rigid part
Initial Pose
Input
Observation SDF
Closest Points Error
Intersection
Loss Function Calculation
EKF
Estimated Pose
Iteration

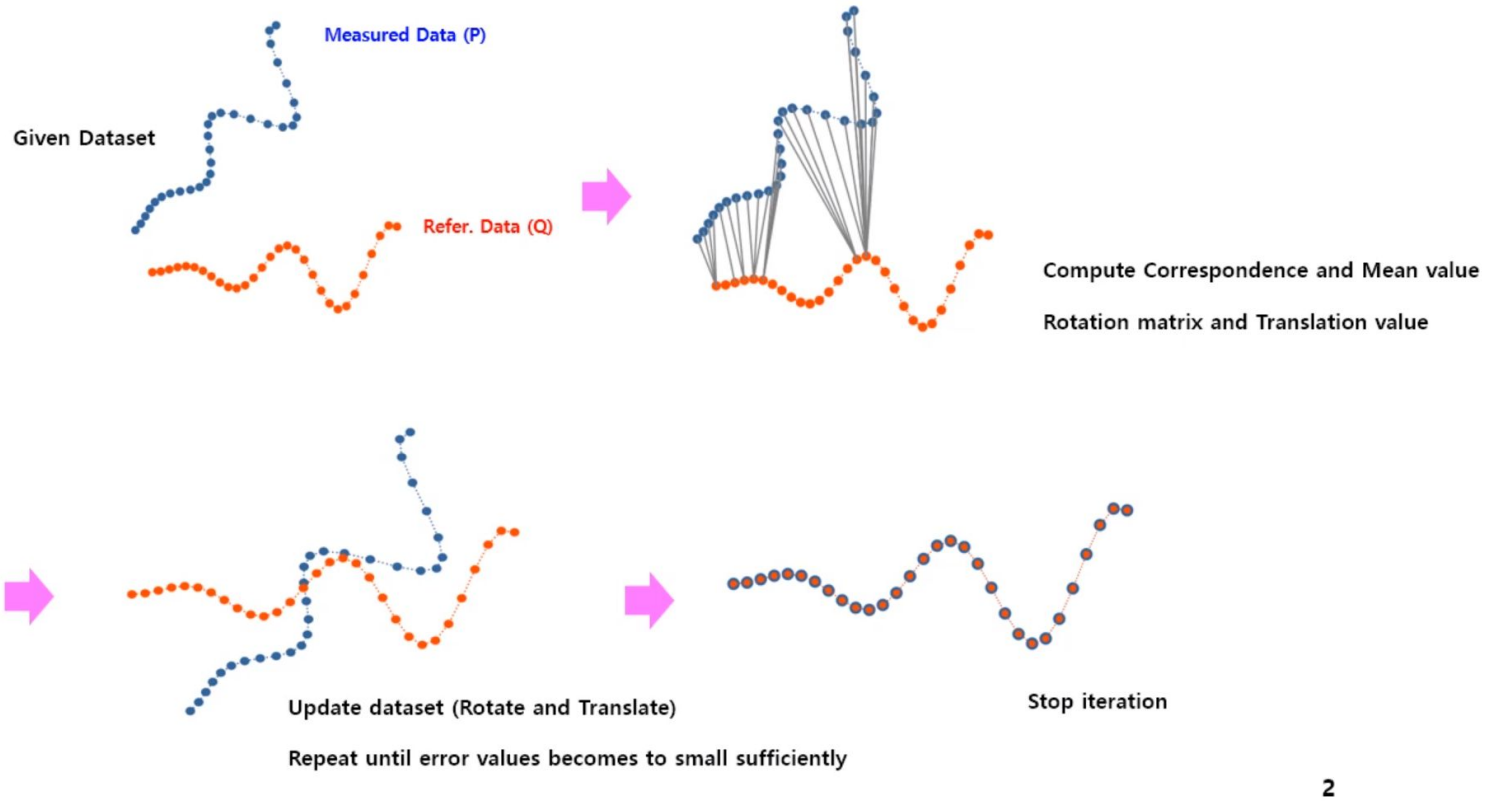
ICP: Iterative closest point

Point clouds generated by depth images

Point clouds of the lockbox's surface generated by previous poses

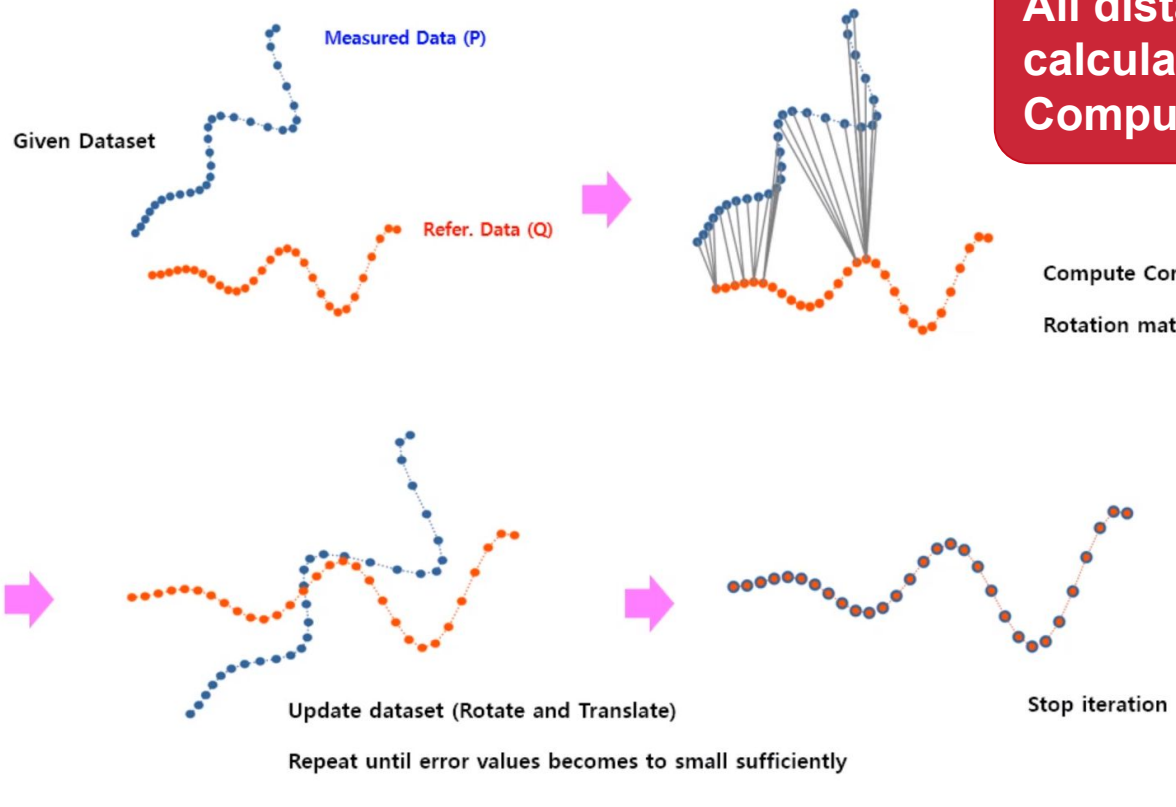
Source: https://www.youtube.com/watch?v=6qVZvKIkJMo

ICP: Iterative closest point



Source: https://www.youtube.com/watch?v=6qVZvKIkJMo

ICP: Iterative closest point



All distances have to be calculated in every iteration. Computationally expensive!

Source: https://www.youtube.com/watch?v=6qVZvKIkJMo

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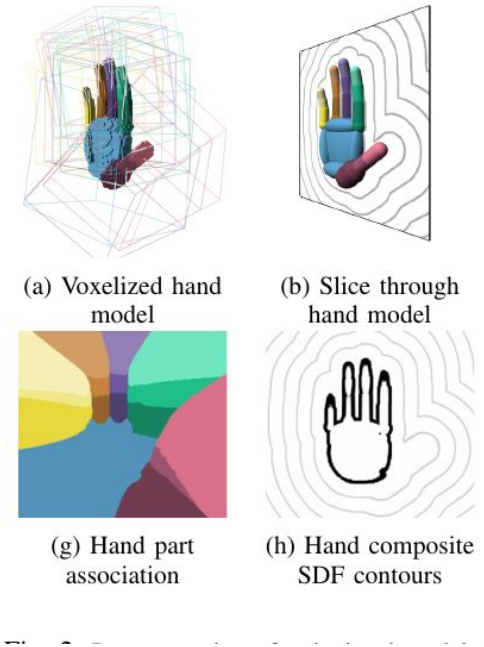
Articulated Object Tracking

$$\hat{\theta} = \arg\min_{\theta} \sum_{\mathbf{u}\in\Omega} ||\mathrm{SDF}_{\mathrm{mod}}\left(\mathbf{x}_{\mathbf{u}}; \theta\right)||^2 \ .$$

θ describes the pose of the model

SDF represents “Signed Distance Function”, which records the distance between points and the surface of the rigid body.

$\mathbf{x}_{\mathbf{u}}$ is the position vector of the measured point.



(a) Voxelized hand model

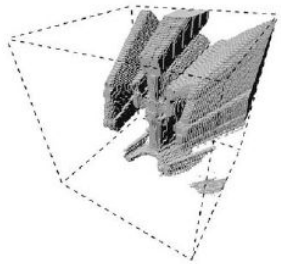
(b) Slice through hand model

(g) Hand part association

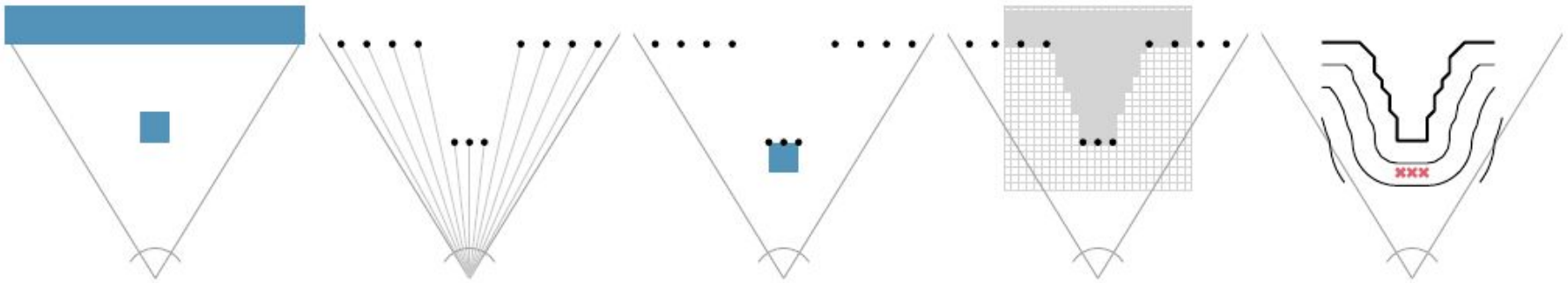
(h) Hand composite SDF contours

Observation SDF:

point cloud



observation SDF



Source: https://www.youtube.com/watch?v=6qVZvKIkJMo

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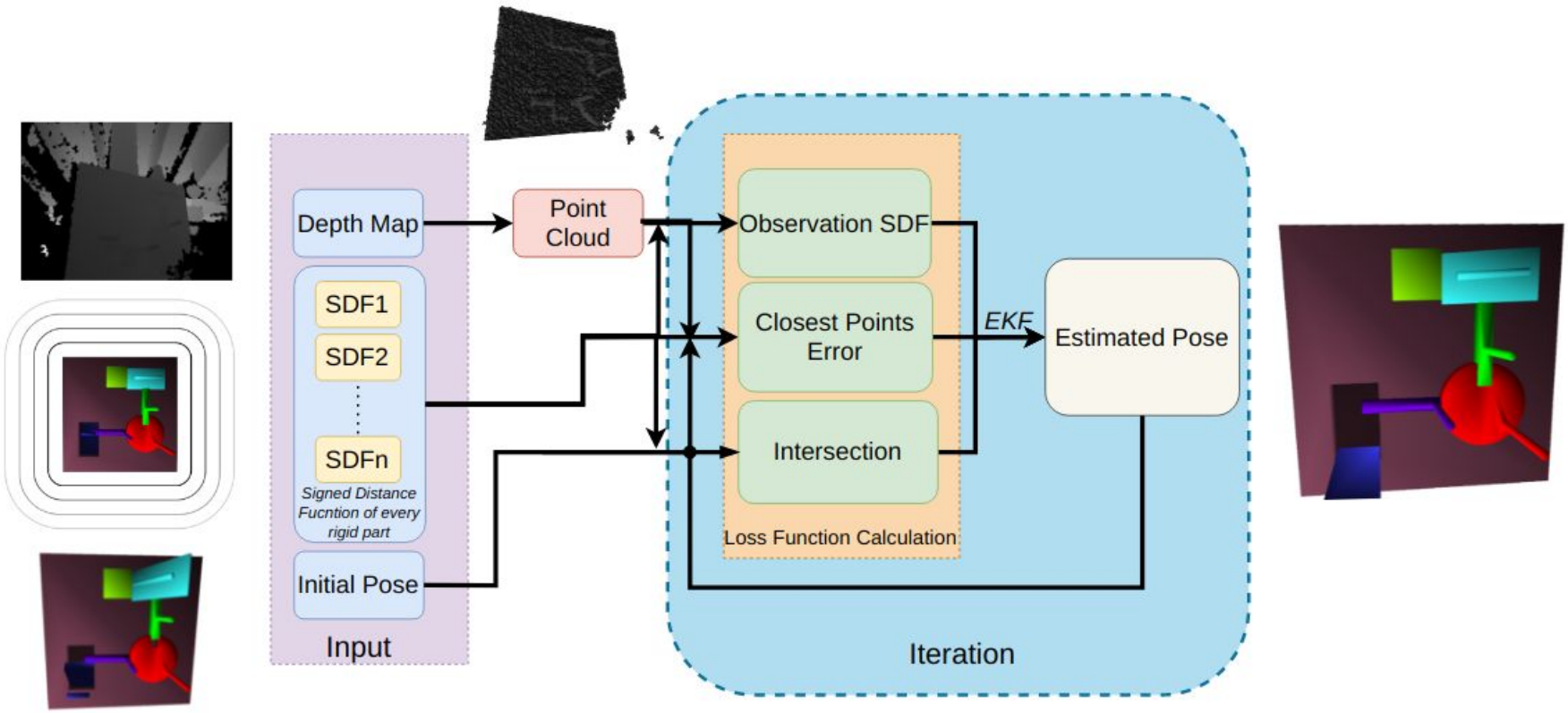
Framework



Intersection Term

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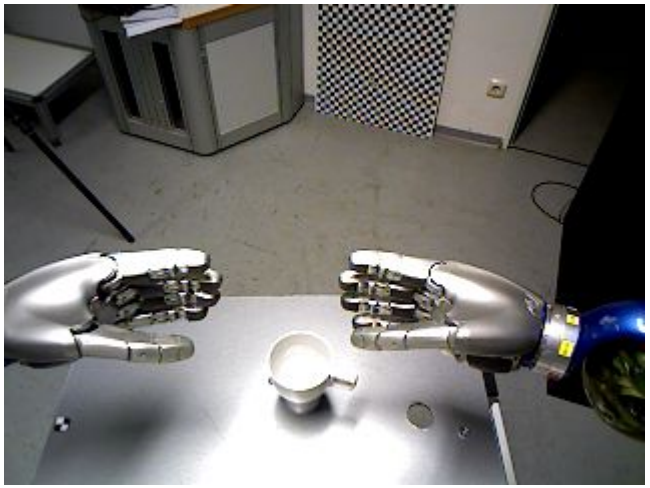
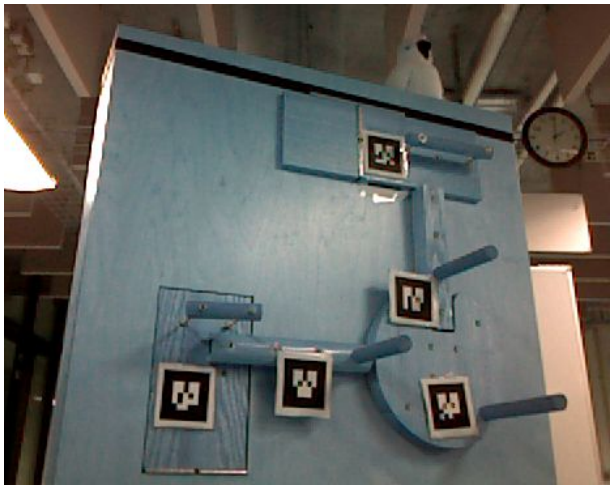
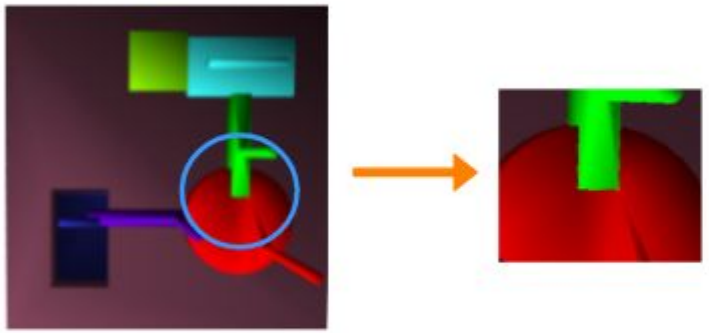
$$\iiint \min(0, f_a(x,y,z))\min(0, f_b(x,y,z))\mathrm{d}x\mathrm{d}y\mathrm{d}z$$

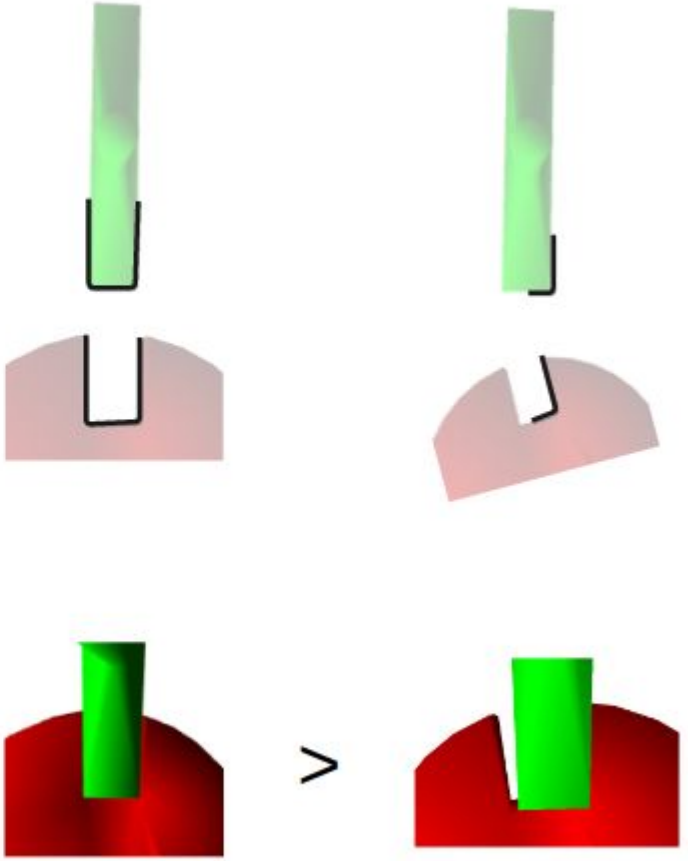
$$\oiint \min(0, f_a^2(x,y,z))\mathrm{d}S_B + \oiint \min(0, f_b^2(x,y,z))\mathrm{d}S_A$$





Intersection Term





Ground Truth

False Result

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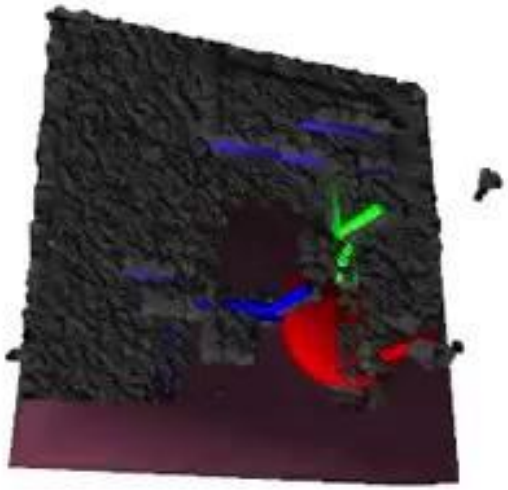
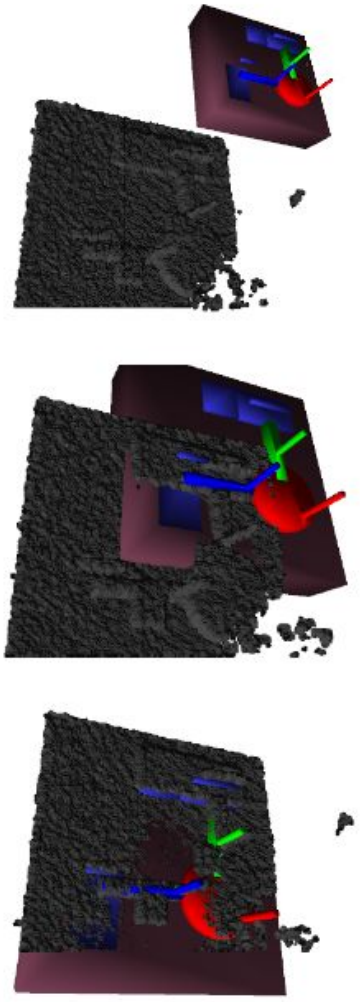
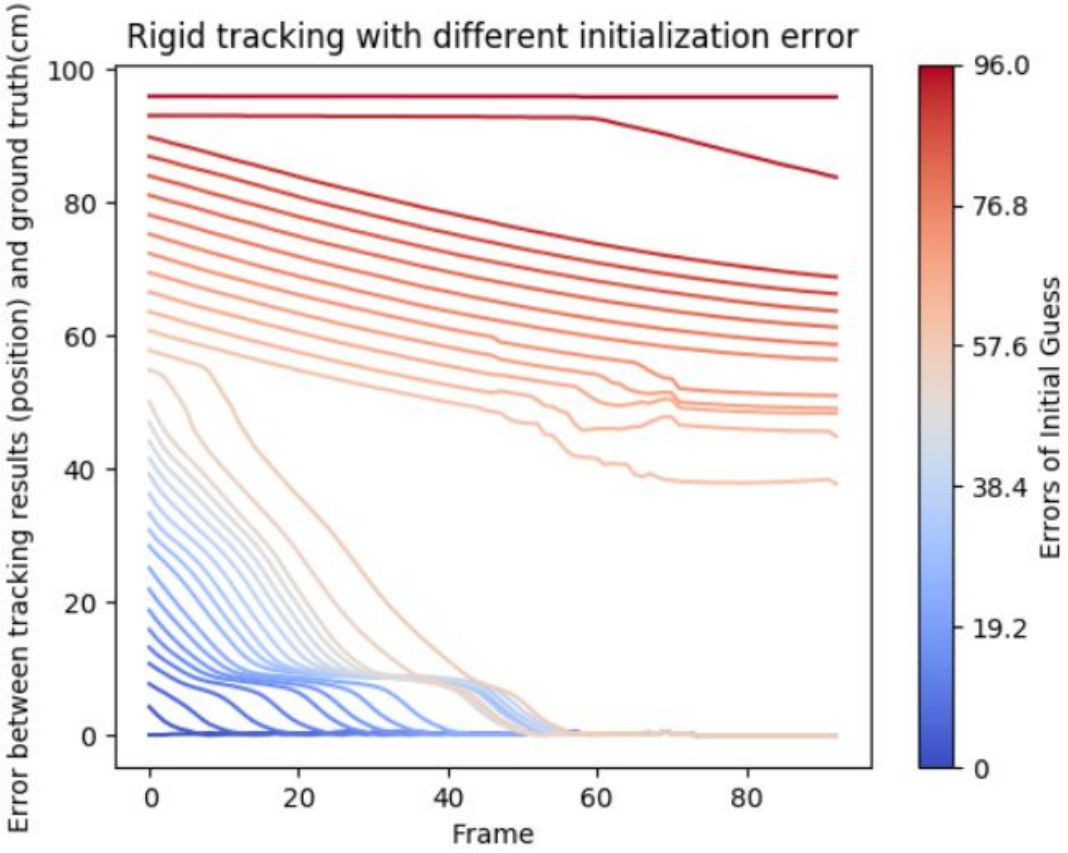
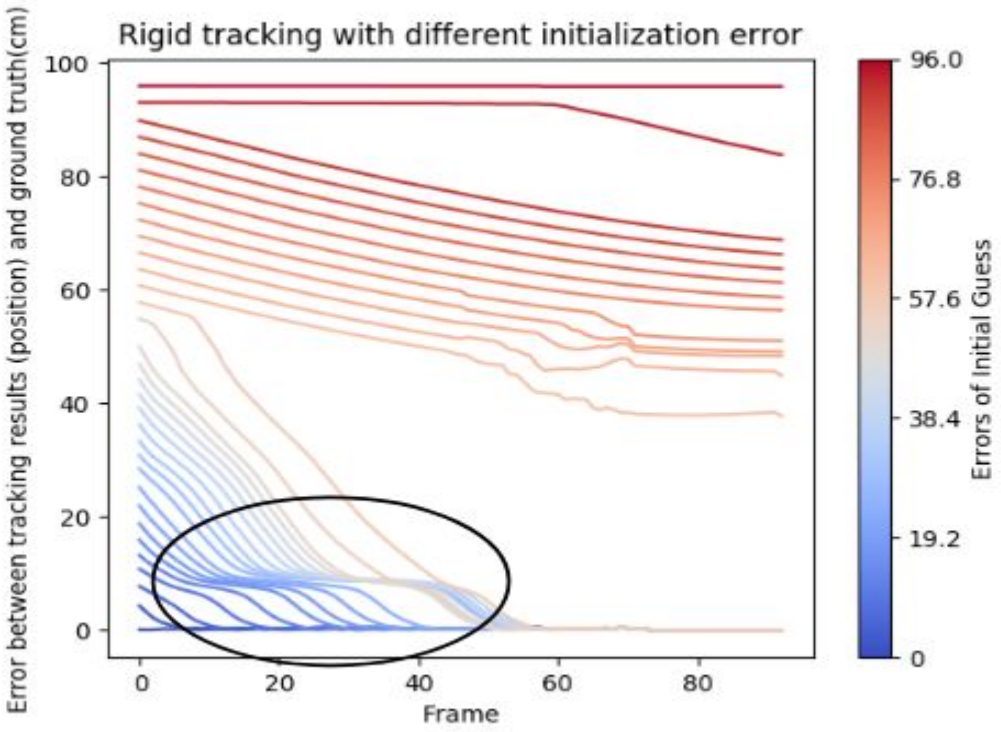
Result

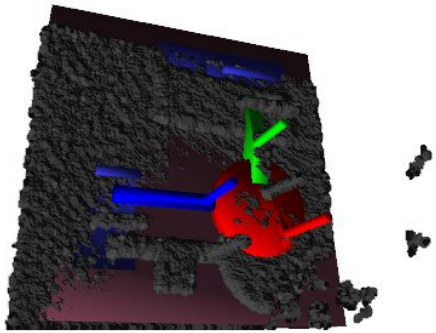


Result

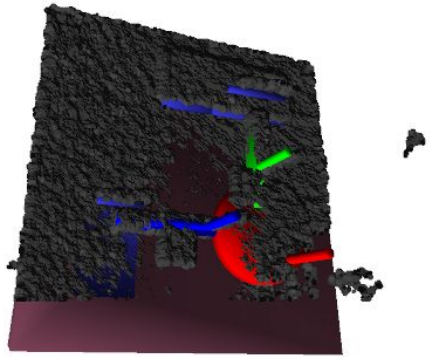



Rigid tracking with different initialization error
Error between tracking results (position) and ground truth(cm)
Frame
Errors of Initial Guess
0
20
40
60
80
100
96.0
76.8
57.6
38.4
19.2
0

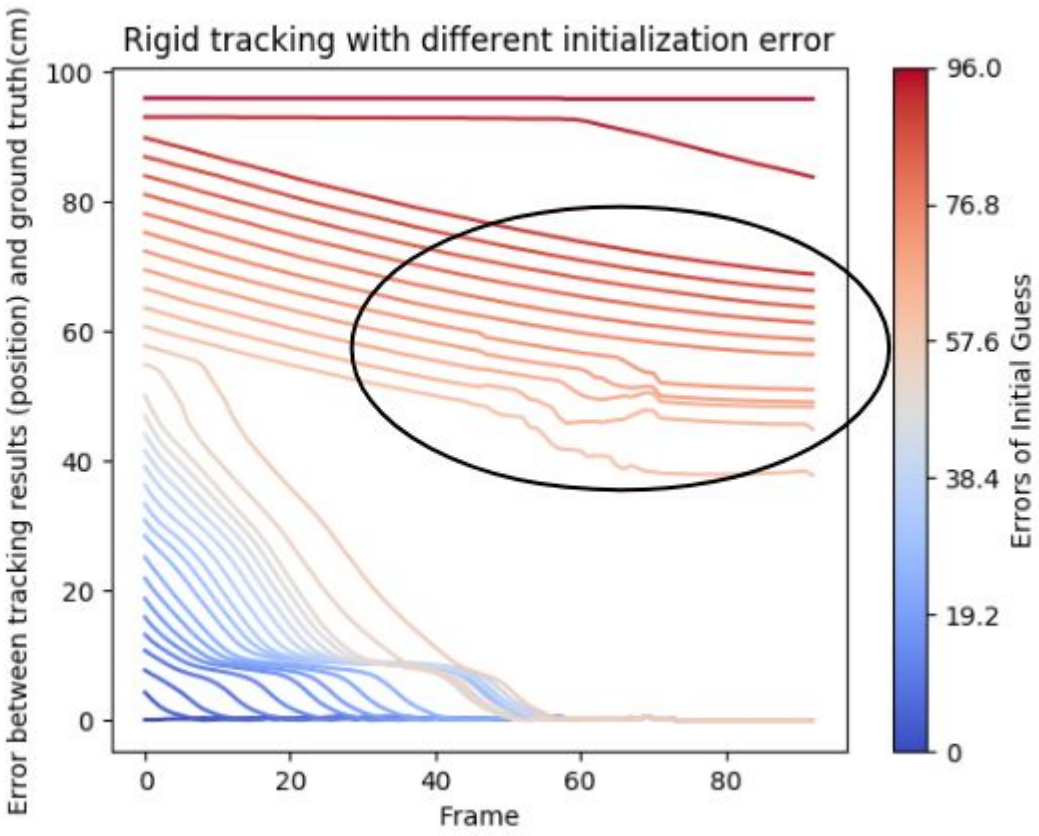




Local Optima



Ground Truth



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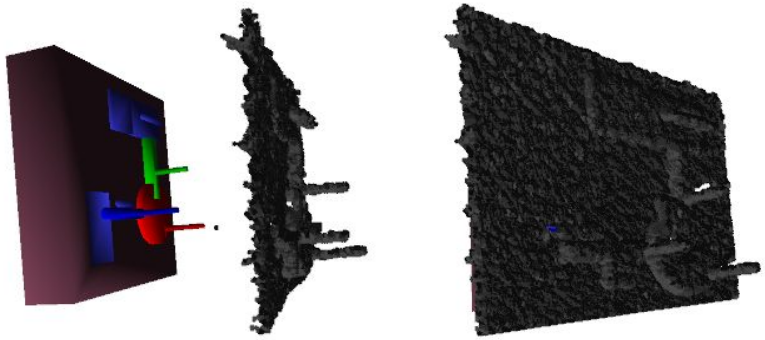
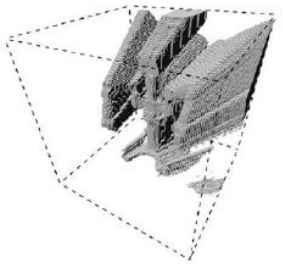


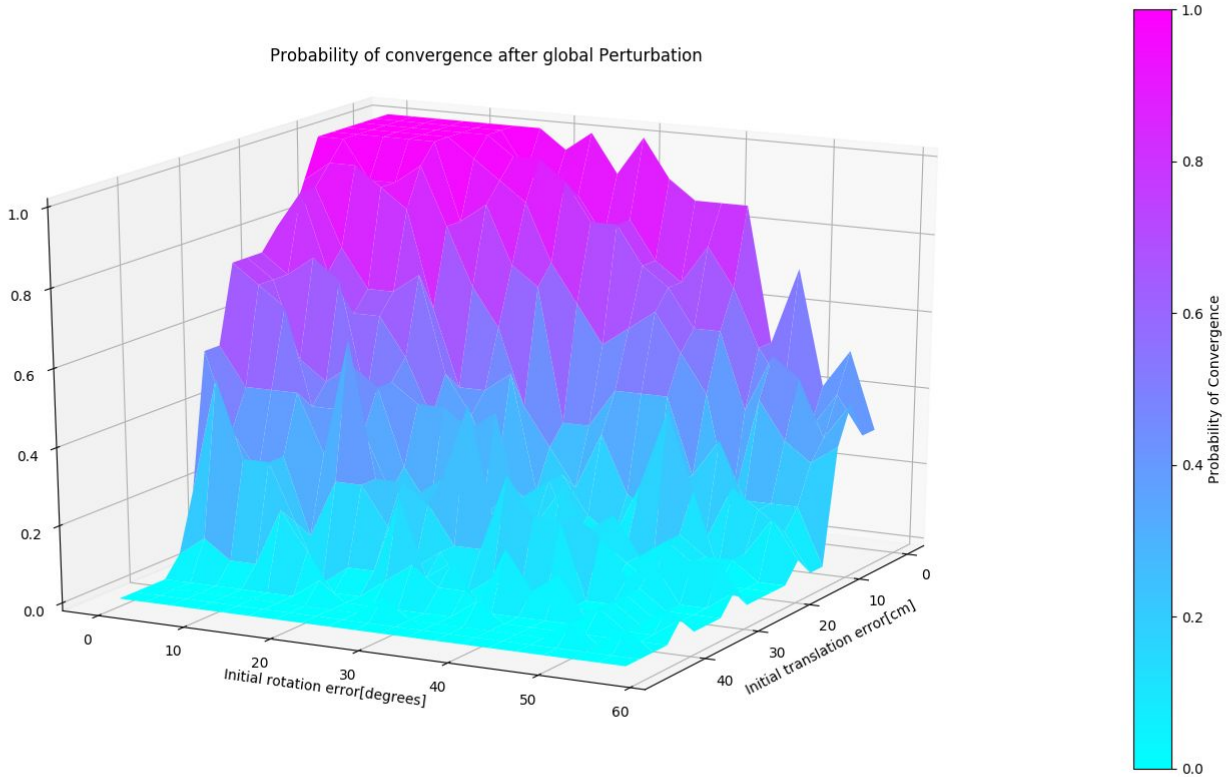
Side View

Front View



observation SDF

Converge ability



Improvement on Intersection term

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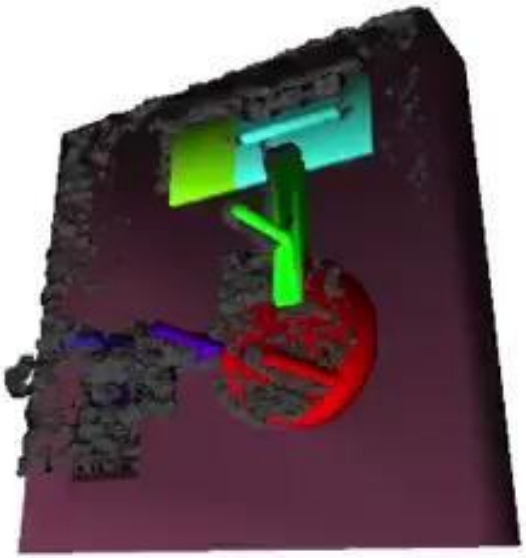

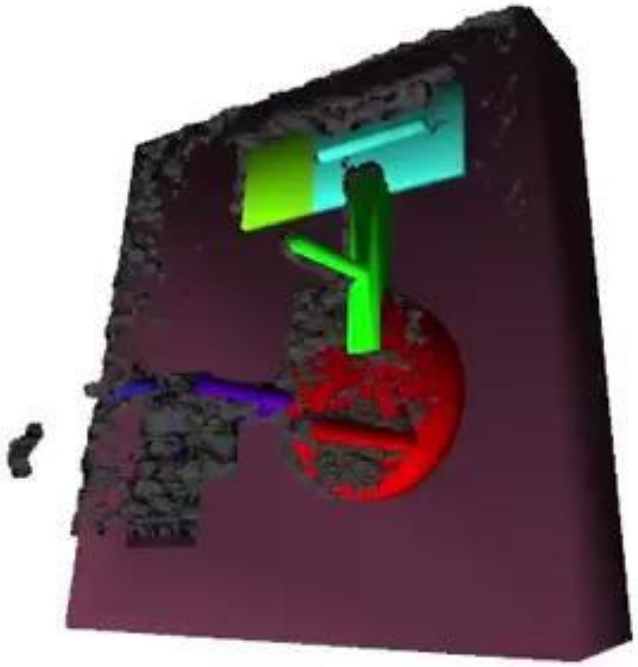

Conclusion

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1. Initial guess is crucial
2. Improvement to Intersection term
3. Future work

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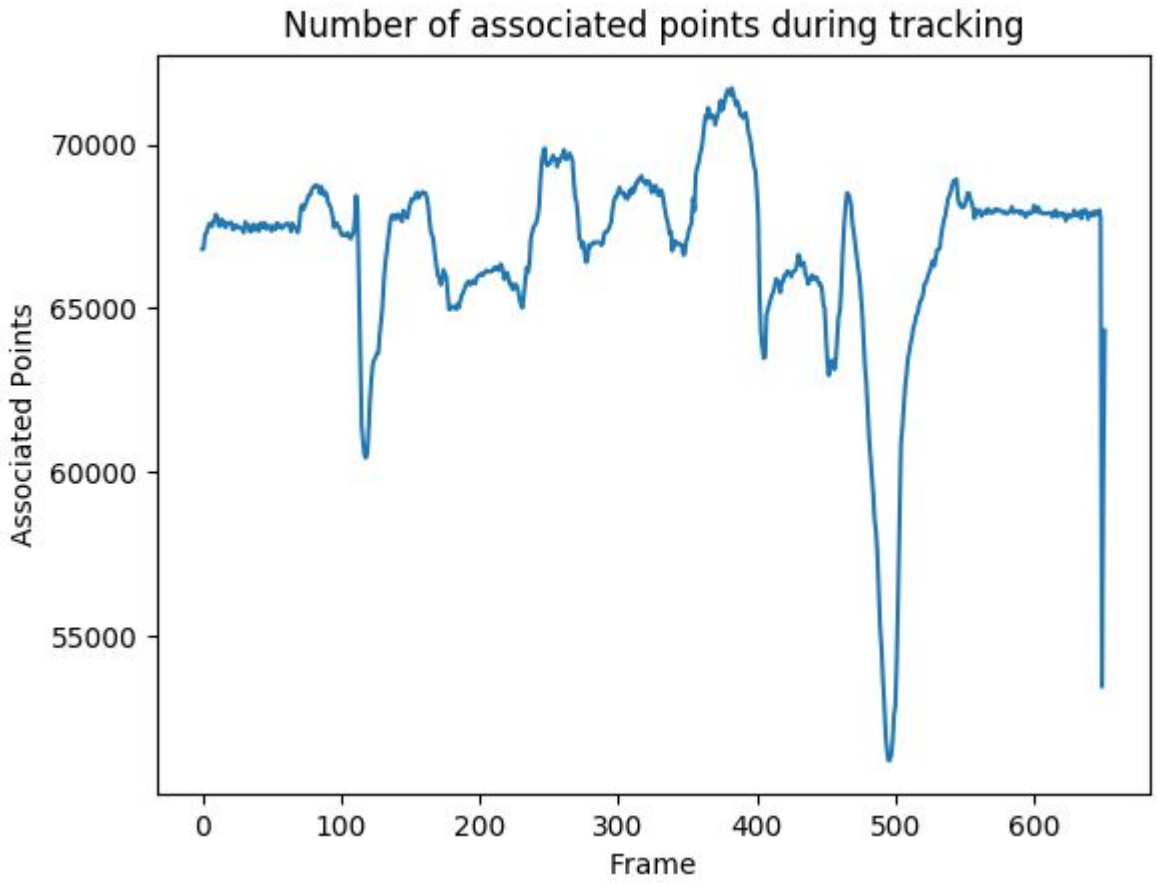
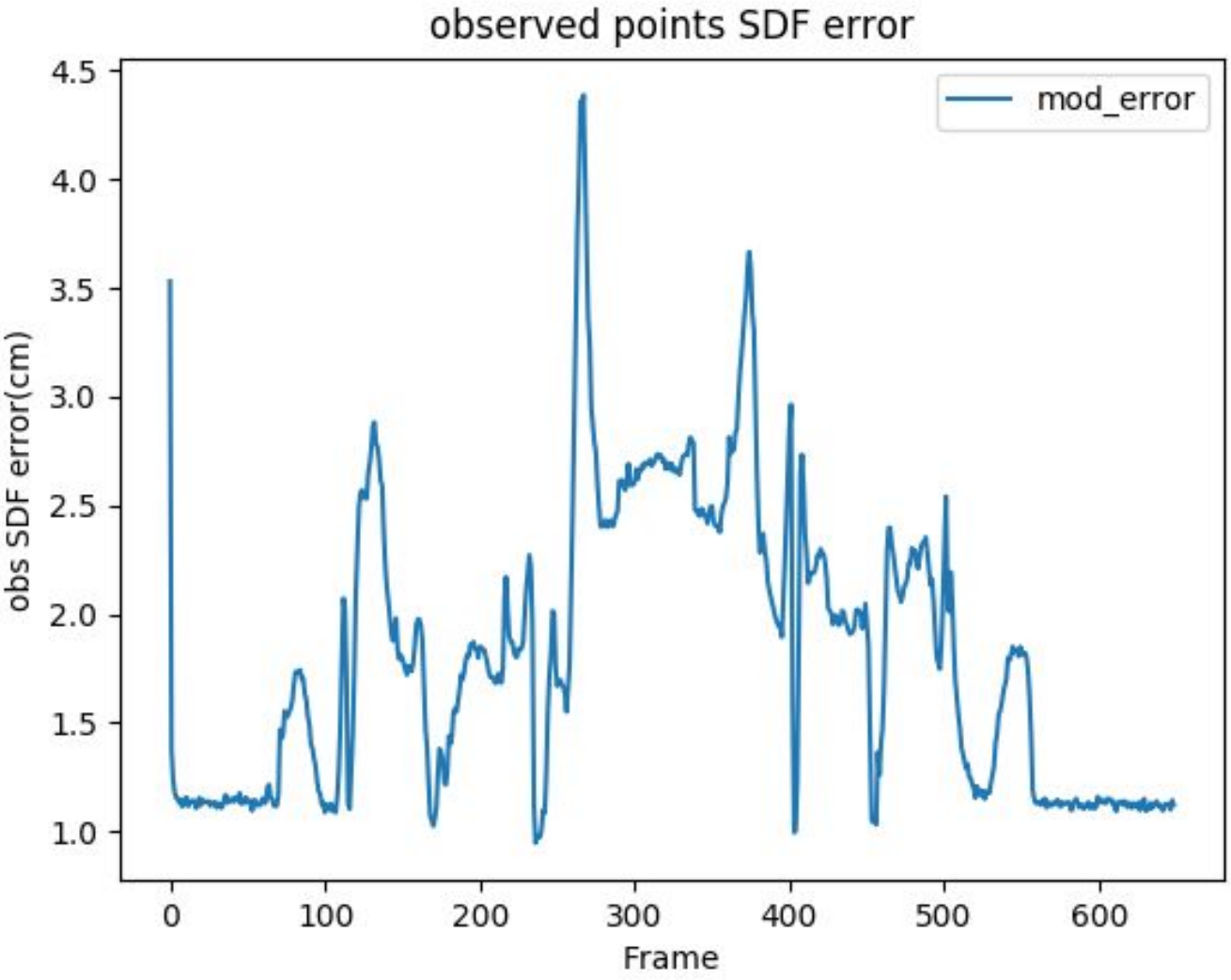
Thank you!


Number of associated points during tracking
Associated Points
70000
65000
60000
55000
0
100
200
300
400
500
600
Frame


observed points SDF error
mod_error
obs SDF error(cm)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
100
200
300
400
500
600
Frame