Local Tracking and Mapping for Direct Visual SLAM

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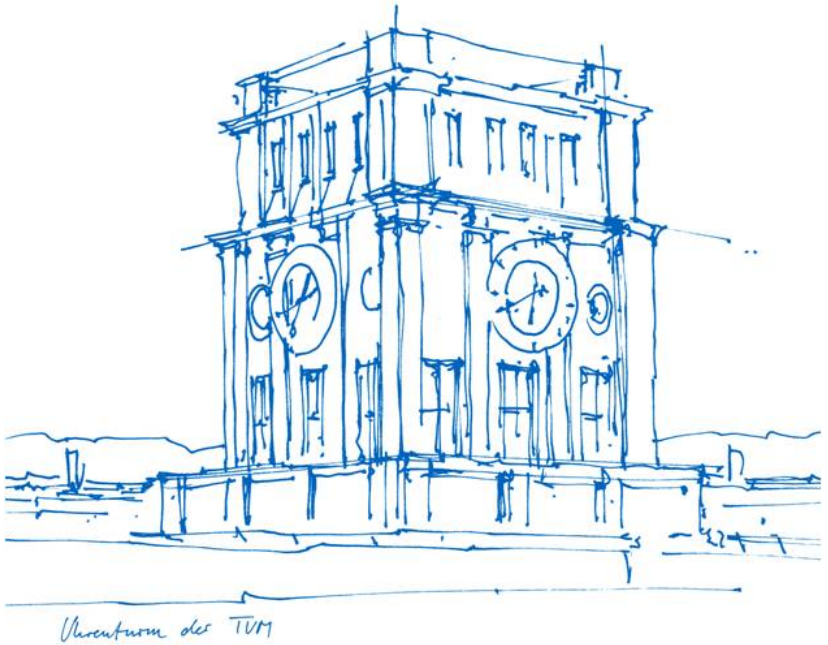
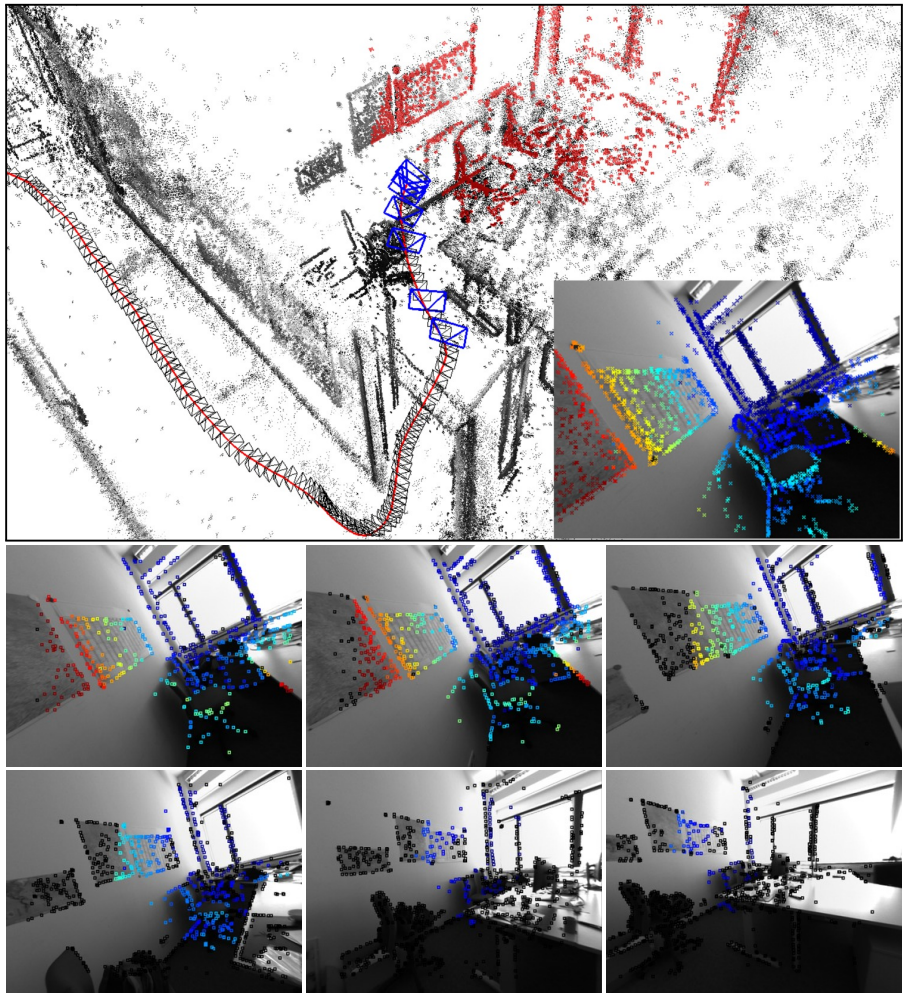


Problem Statement



Direct Sparse Odometry, Engel et al.

Problem Statement

When doing **marginalization** of keyframes / points in VO,

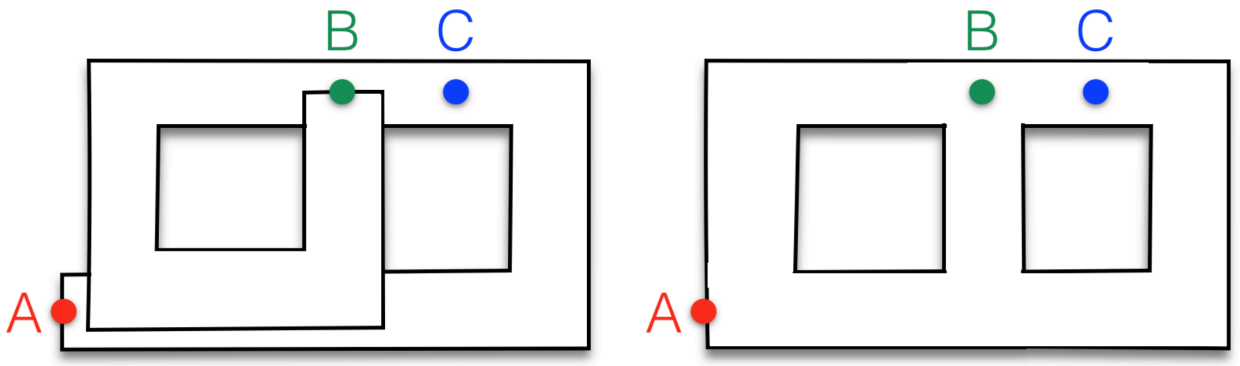
reusing map points

(when revisiting already mapped areas)

is **not possible**.

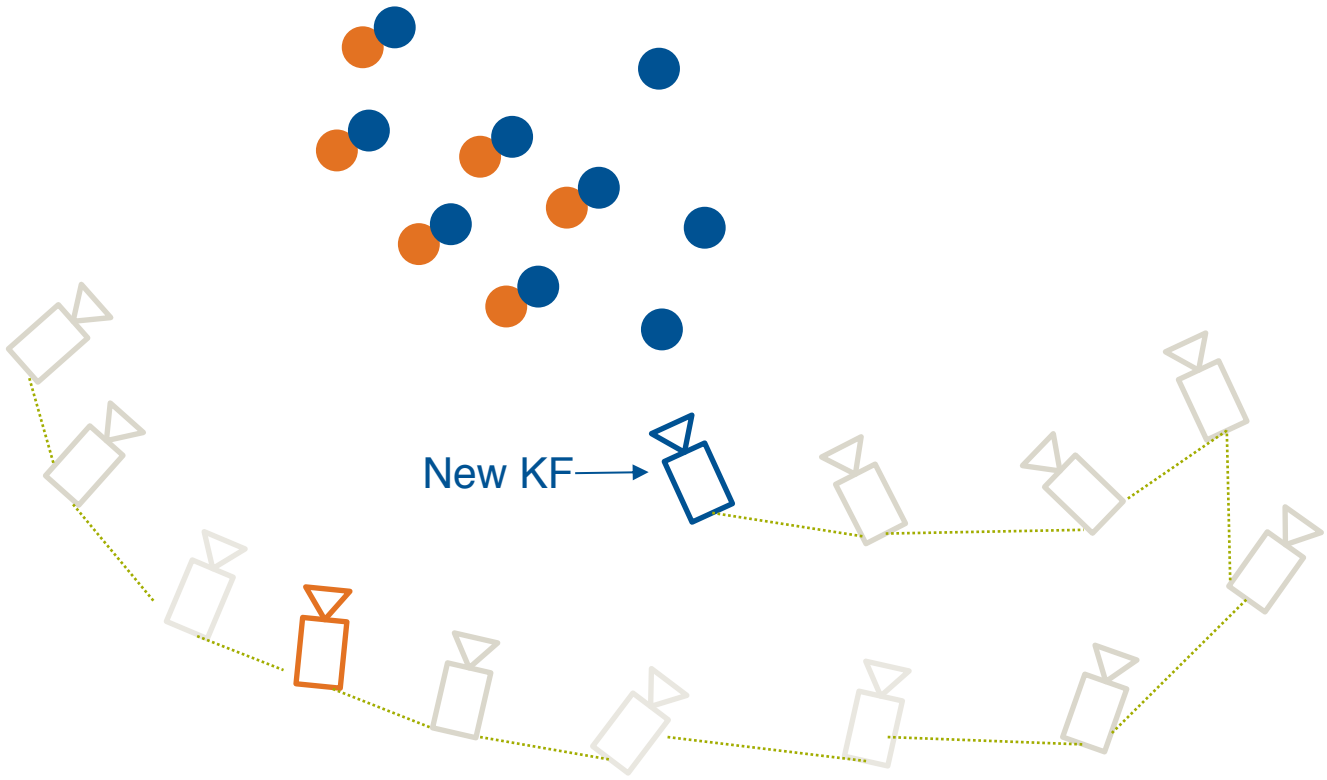
Problem Statement

Odometry ➡ SLAM

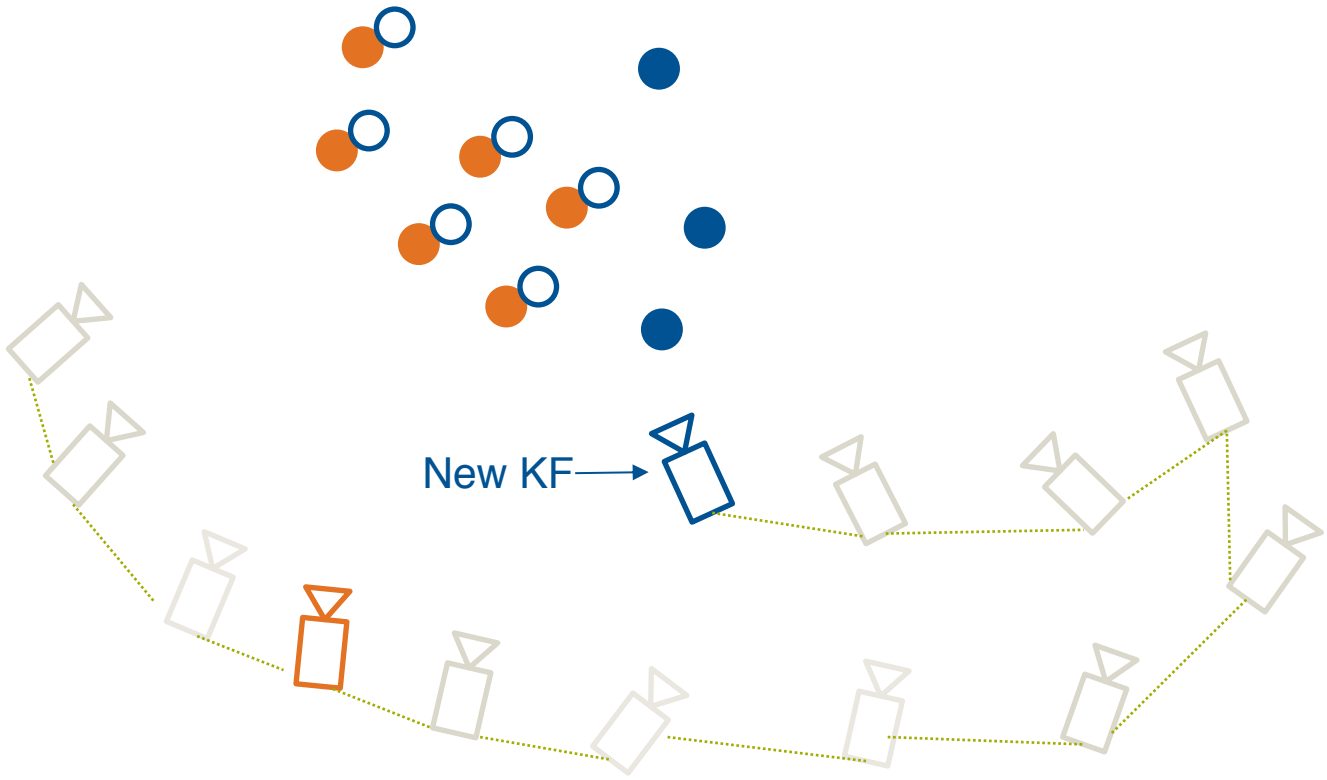


Past, Present, and Future of Simultaneous Localization And Mapping: Towards the Robust-Perception Age, Cadena et al.

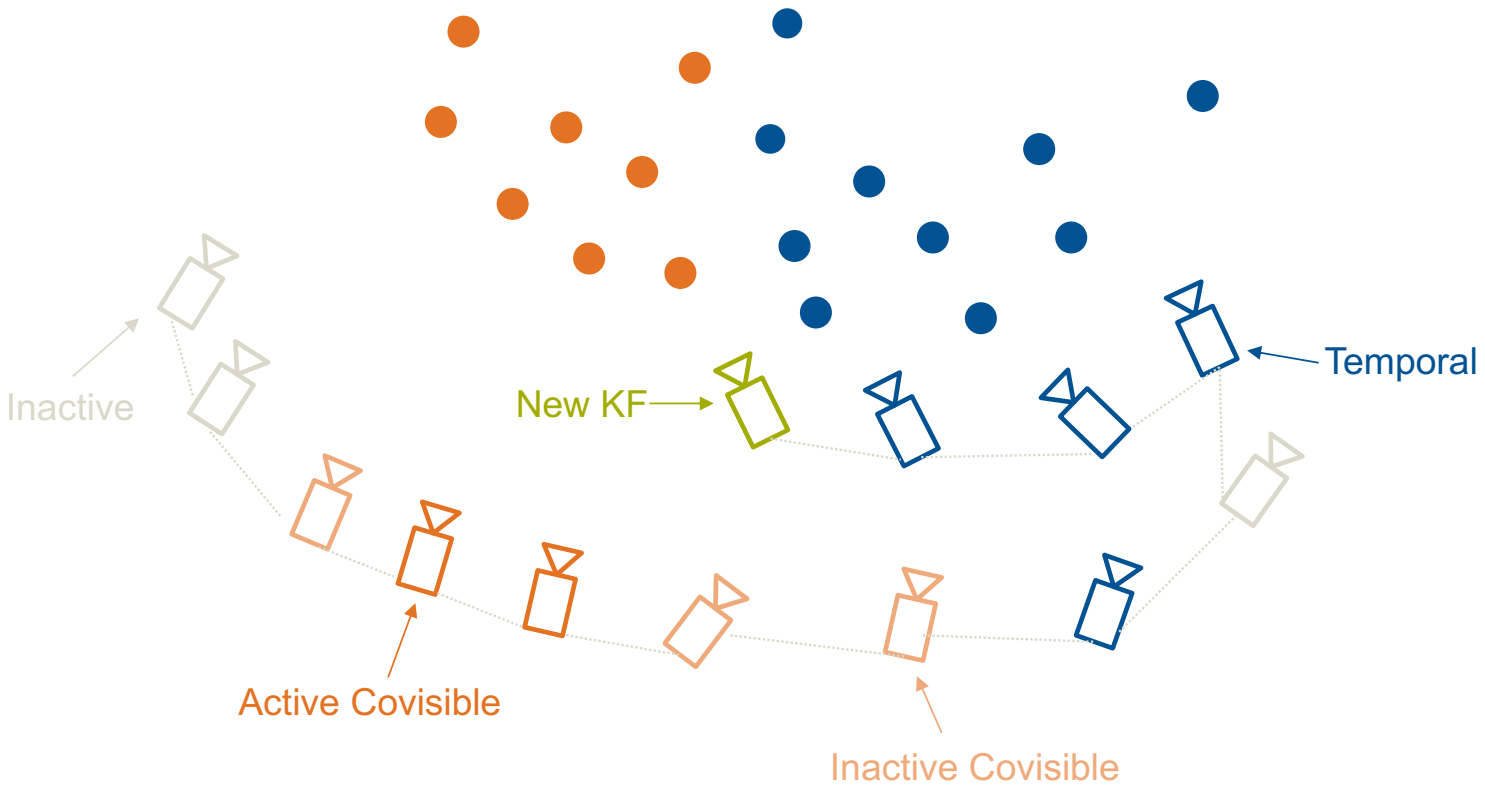
Problem Statement



Problem Statement

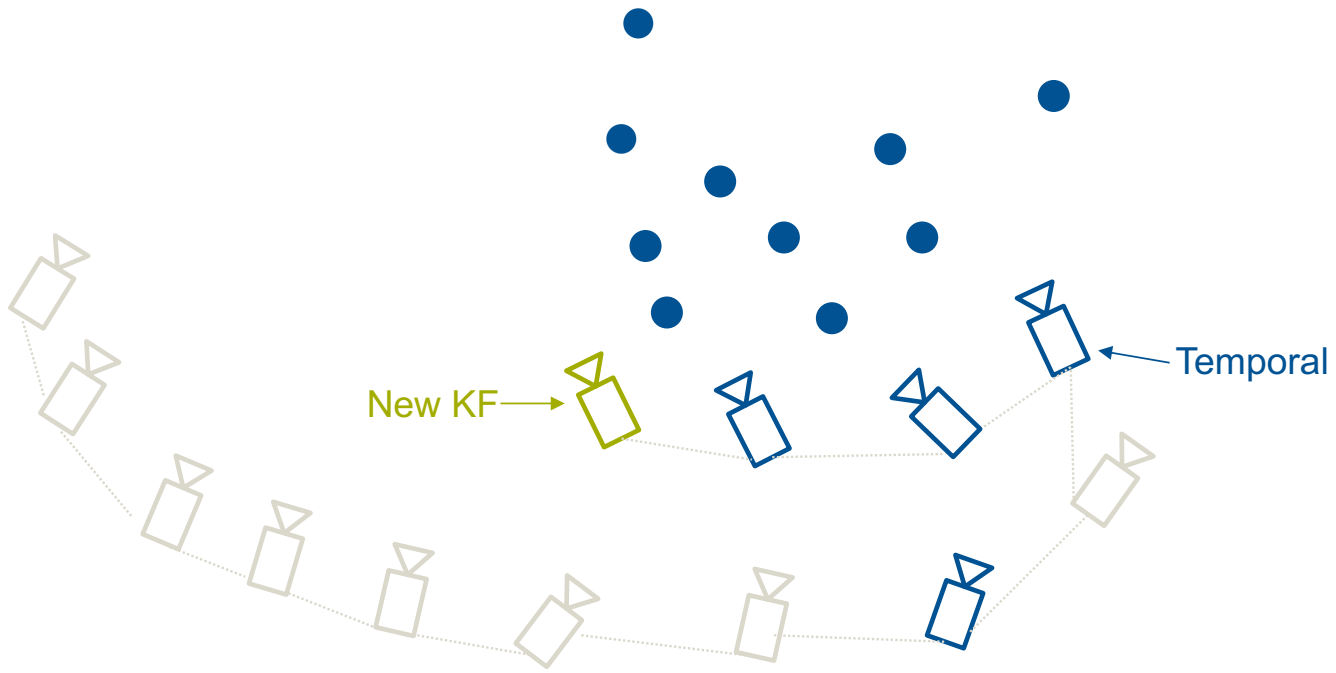


Approach

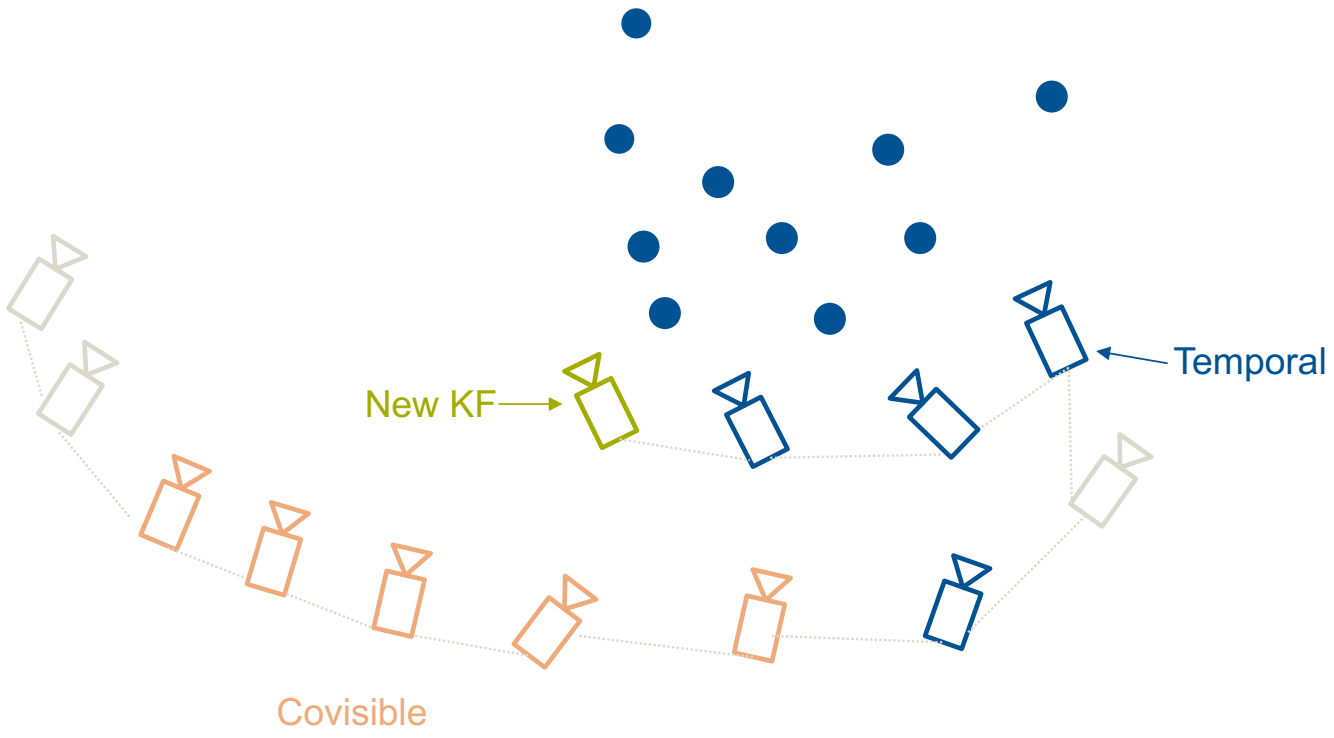


Original idea from: *Direct Sparse Mapping*, Zubizarreta et al.

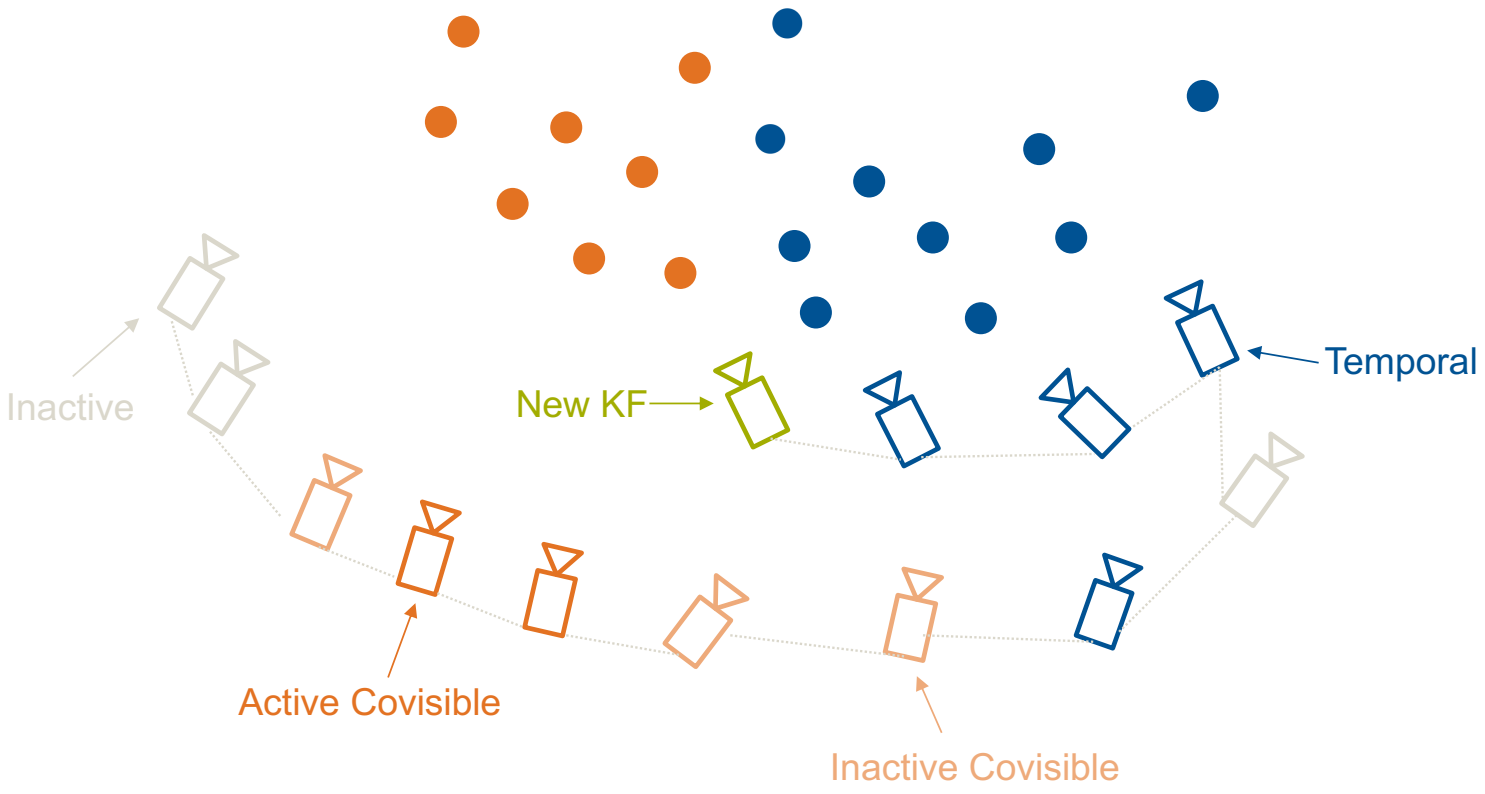
Approach



Approach

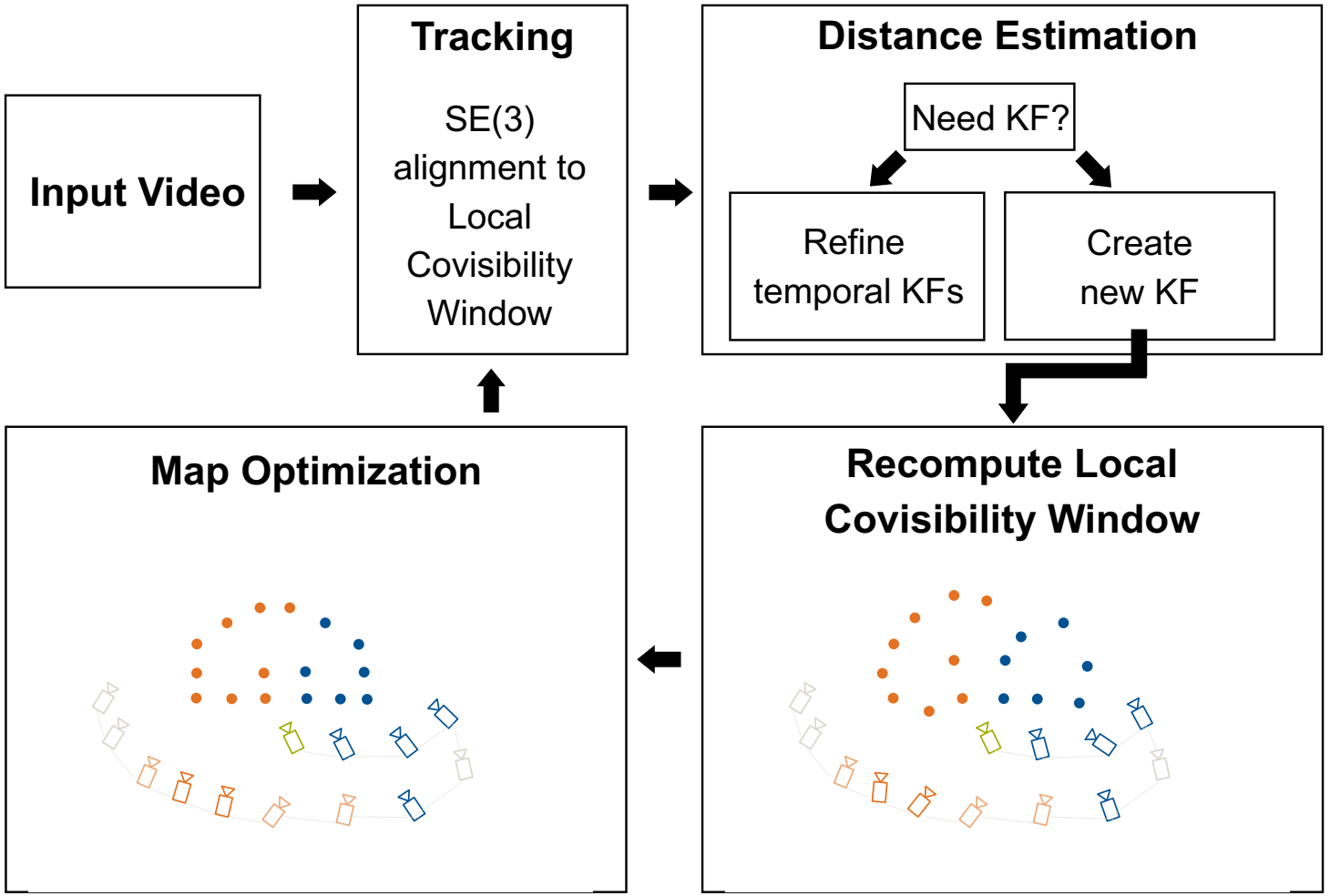


Approach


Inactive
New KF
Temporal
Active Covisible
Inactive Covisible

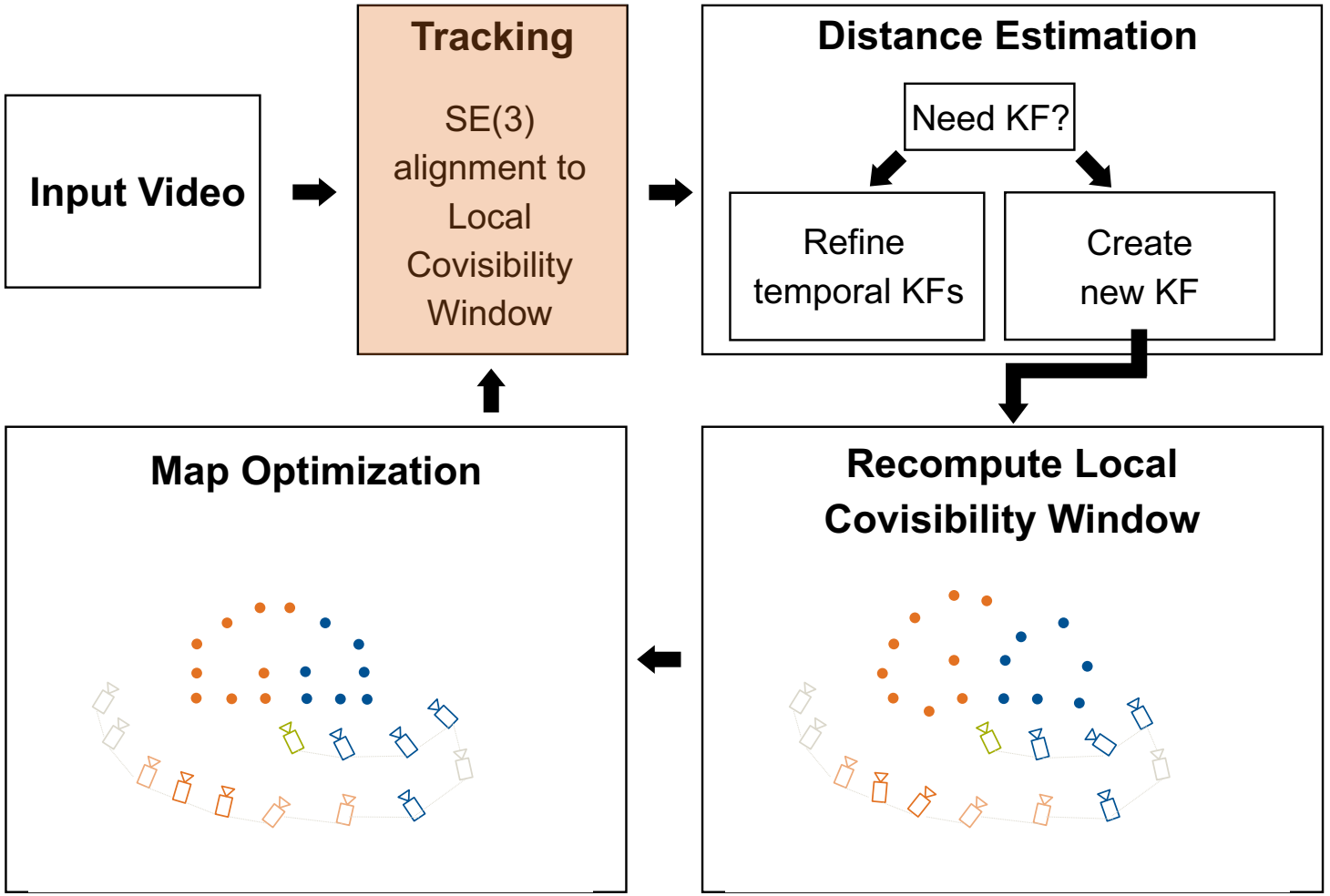
Approach

Overview



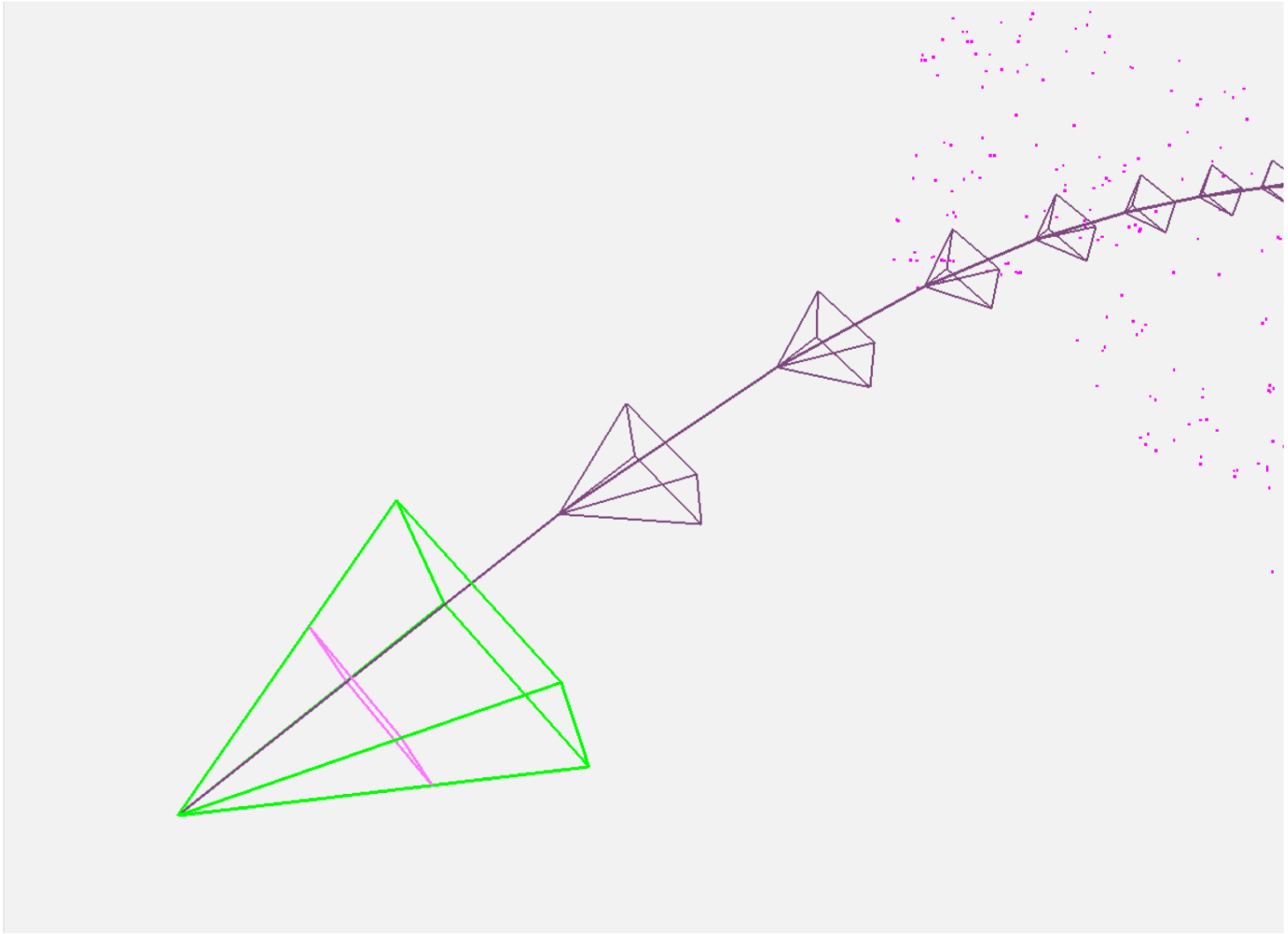
Approach

Overview



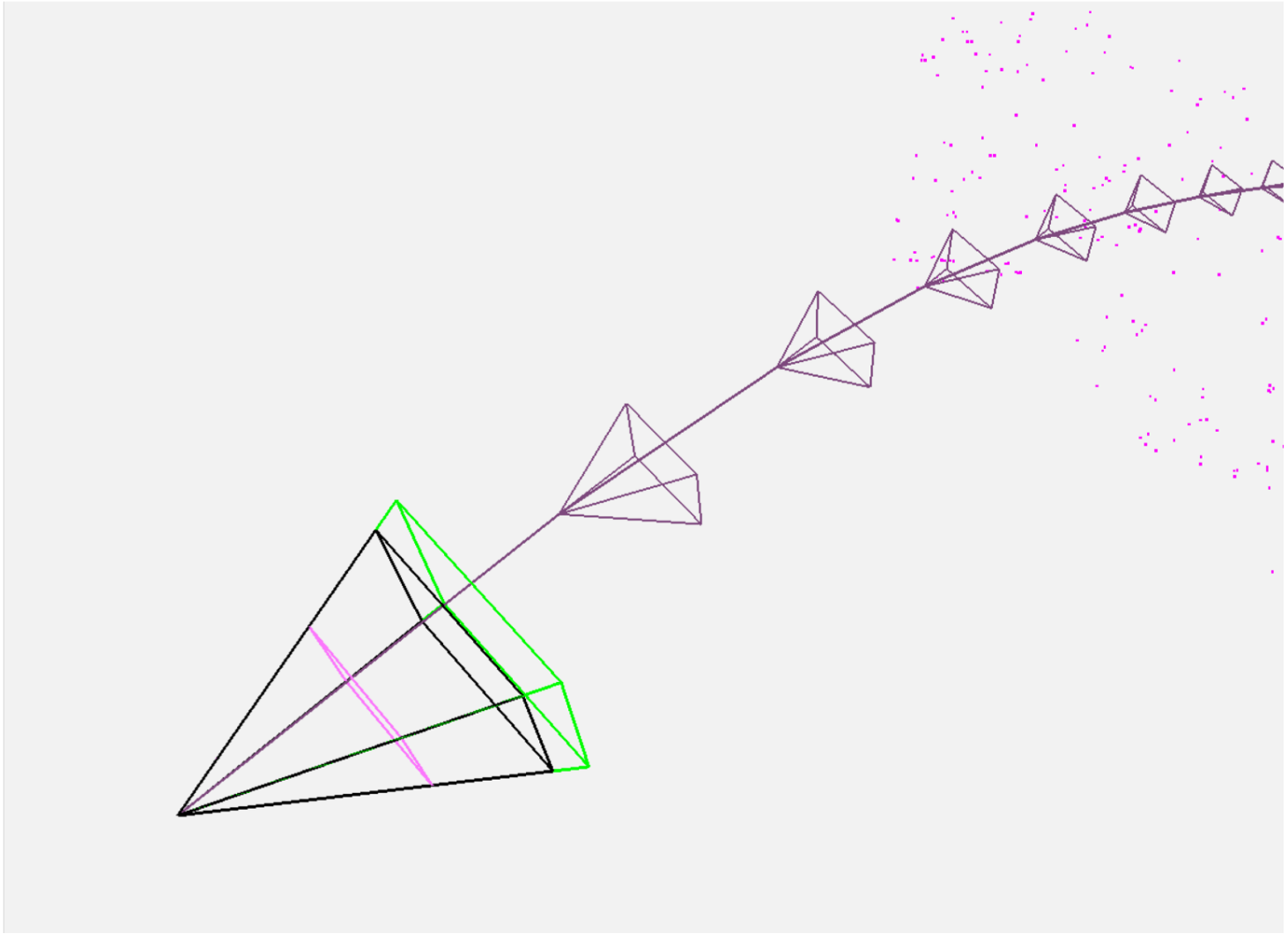
Approach

Tracking



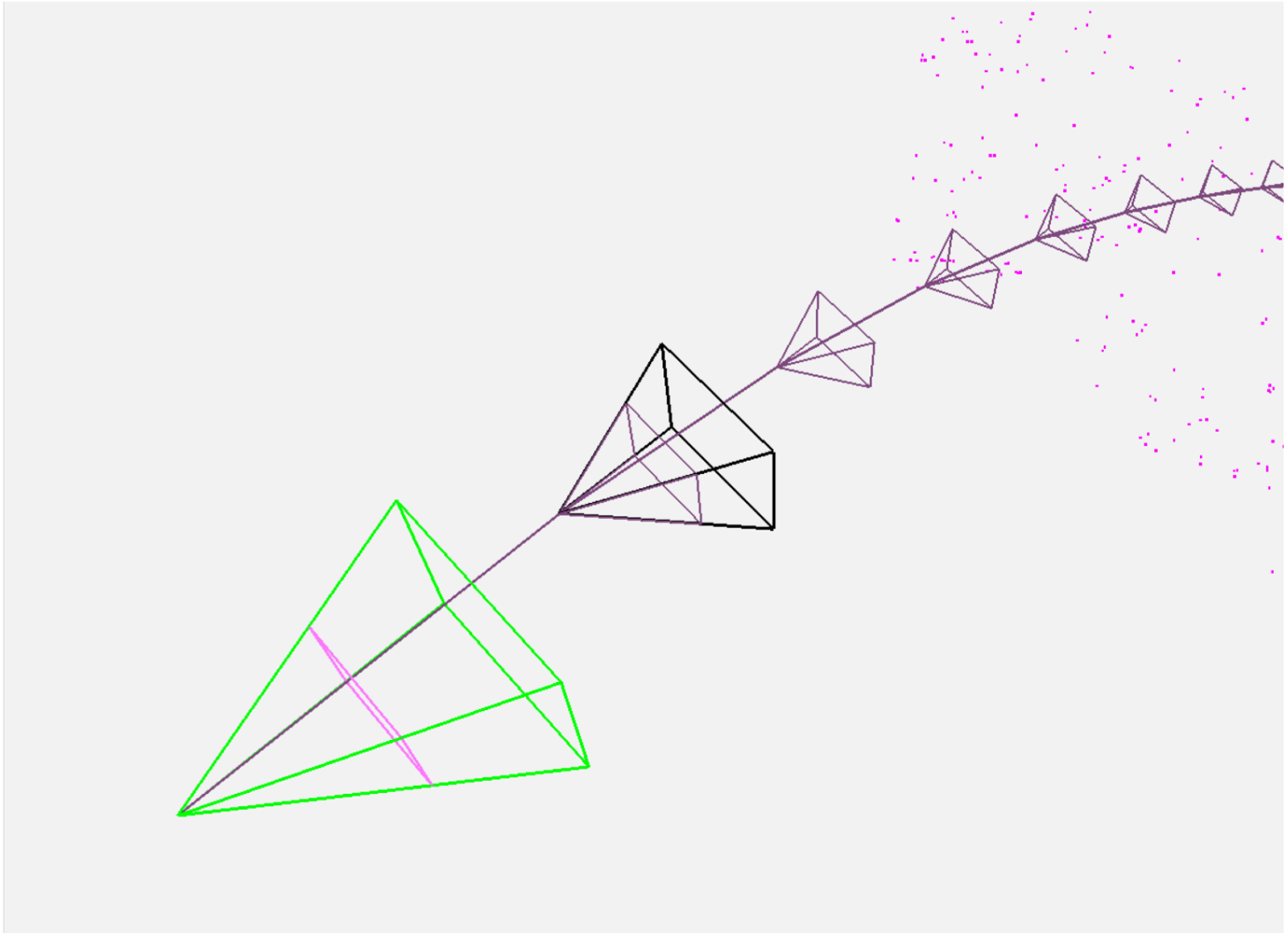
Approach

Tracking



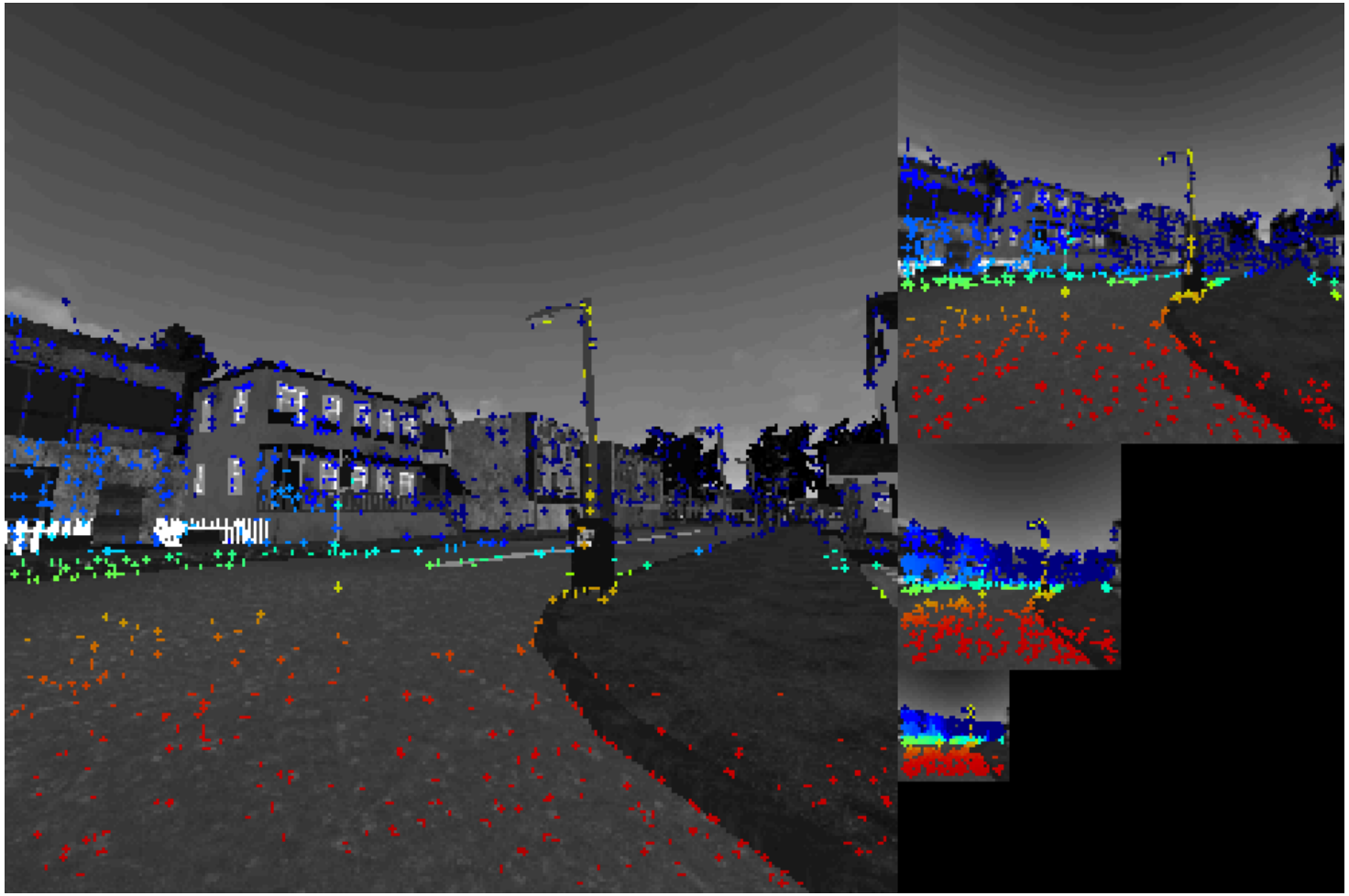
Approach

Tracking



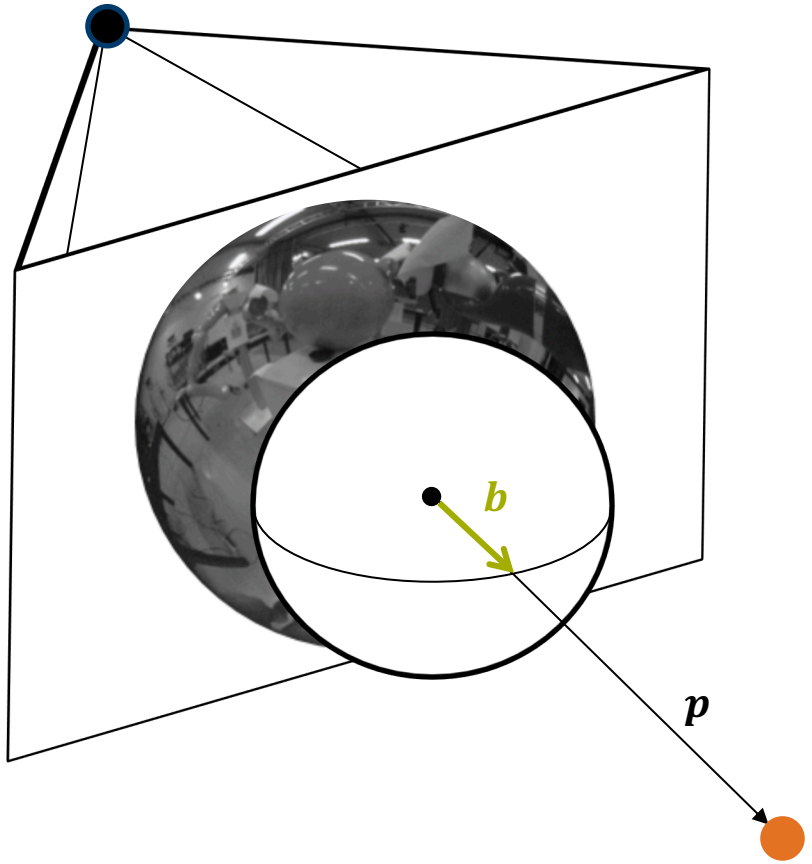
Approach

Building the Image Pyramids



Approach

(Inverse Distance Formulation)



$d_{\boldsymbol{p}} :=$ Inverse distance

$$d_{\boldsymbol{p}} = \frac{1}{\|\boldsymbol{p}\|}$$

$$\boldsymbol{p} = \|\boldsymbol{p}\|\,\boldsymbol{b} = \frac{\boldsymbol{b}}{d_{\boldsymbol{p}}}$$

Approach

Tracking

Direct Image Alignment

Forward Additive

$$r_i(\mathbf{T} \oplus \boldsymbol{\xi}) = I_t(w(\mathbf{T} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_h(\mathbf{u})$$

Inverse Compositional

$$r_i(\boldsymbol{\xi}) = I_h(w(\mathbf{I} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_t(w(\mathbf{T}, \mathbf{u}))$$

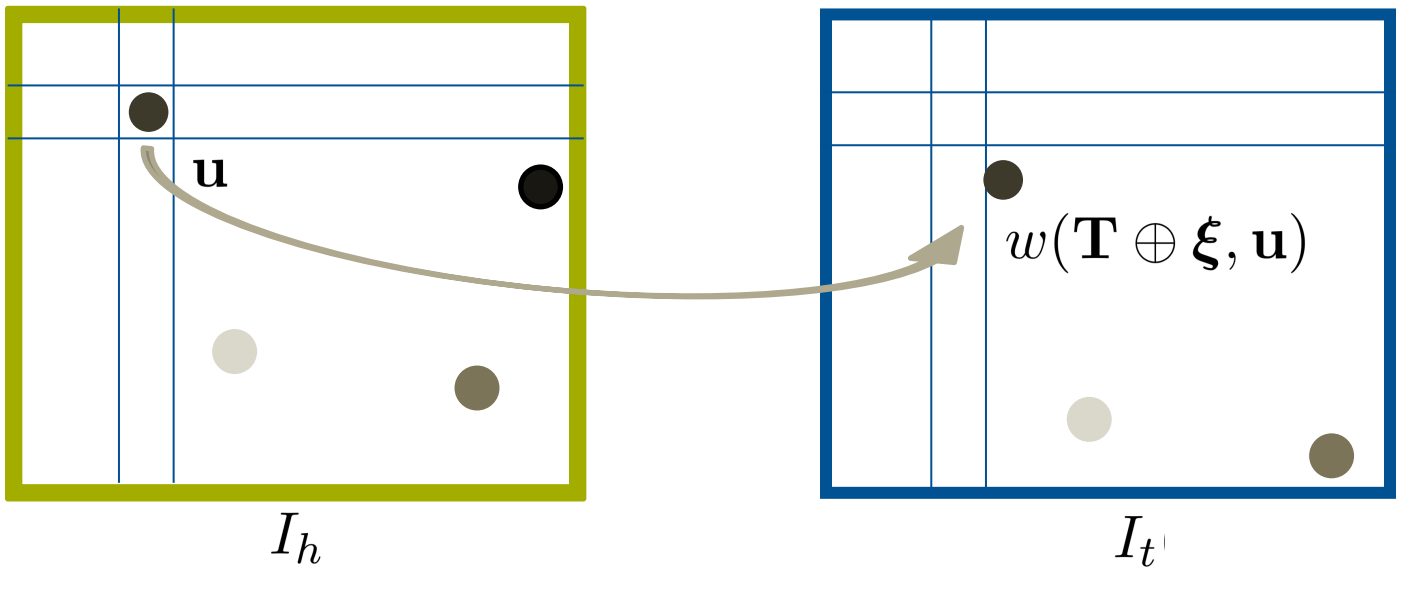
Approach

Tracking

Direct Image Alignment

Forward Additive

$$r_i(\mathbf{T} \oplus \boldsymbol{\xi}) = I_t(w(\mathbf{T} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_h(\mathbf{u})$$



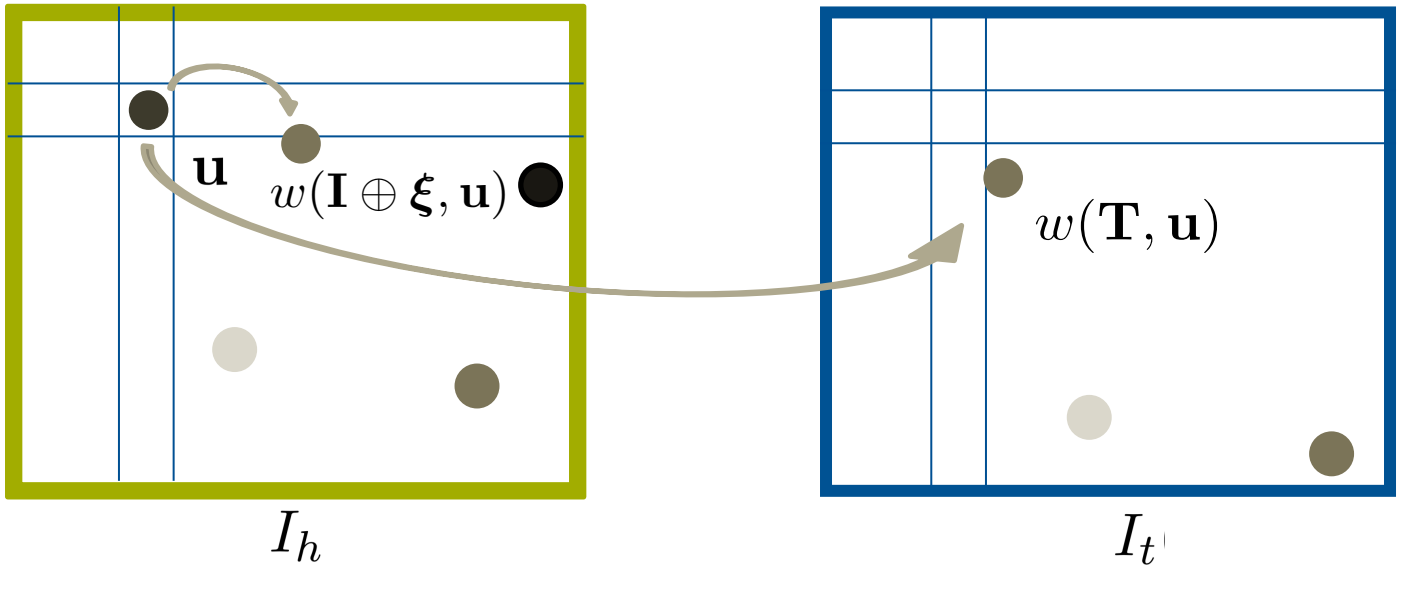
Approach

Tracking

Direct Image Alignment

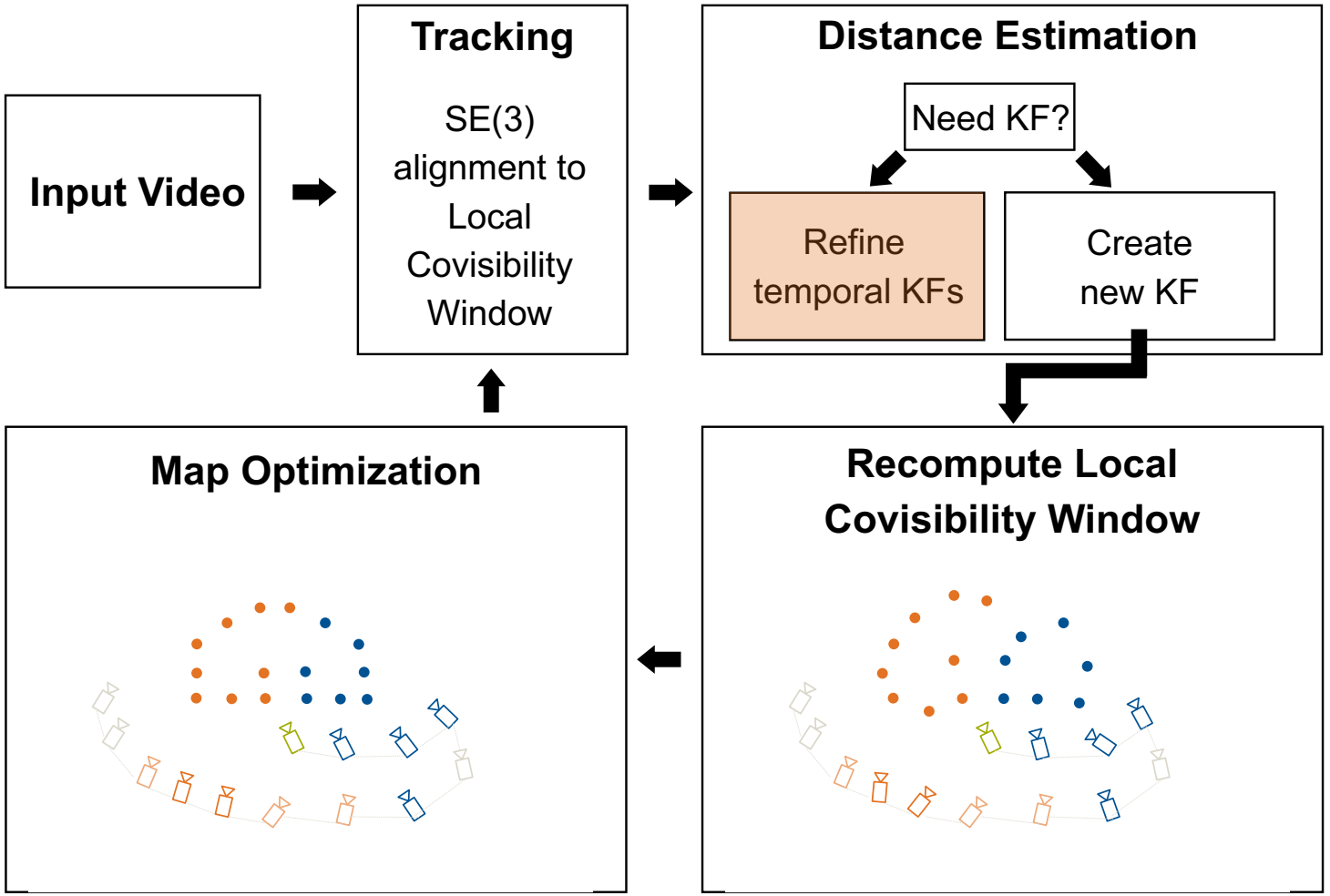
Inverse Compositional

$$r_i(\boldsymbol{\xi}) = I_h(w(\mathbf{I} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_t(w(\mathbf{T}, \mathbf{u}))$$



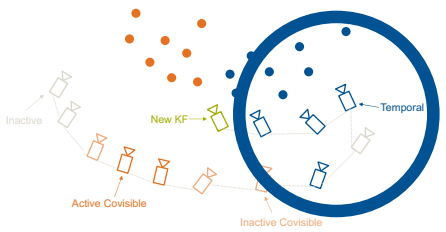
Approach

Overview



Approach

Candidate Point Tracking



Epipolar Curve Search

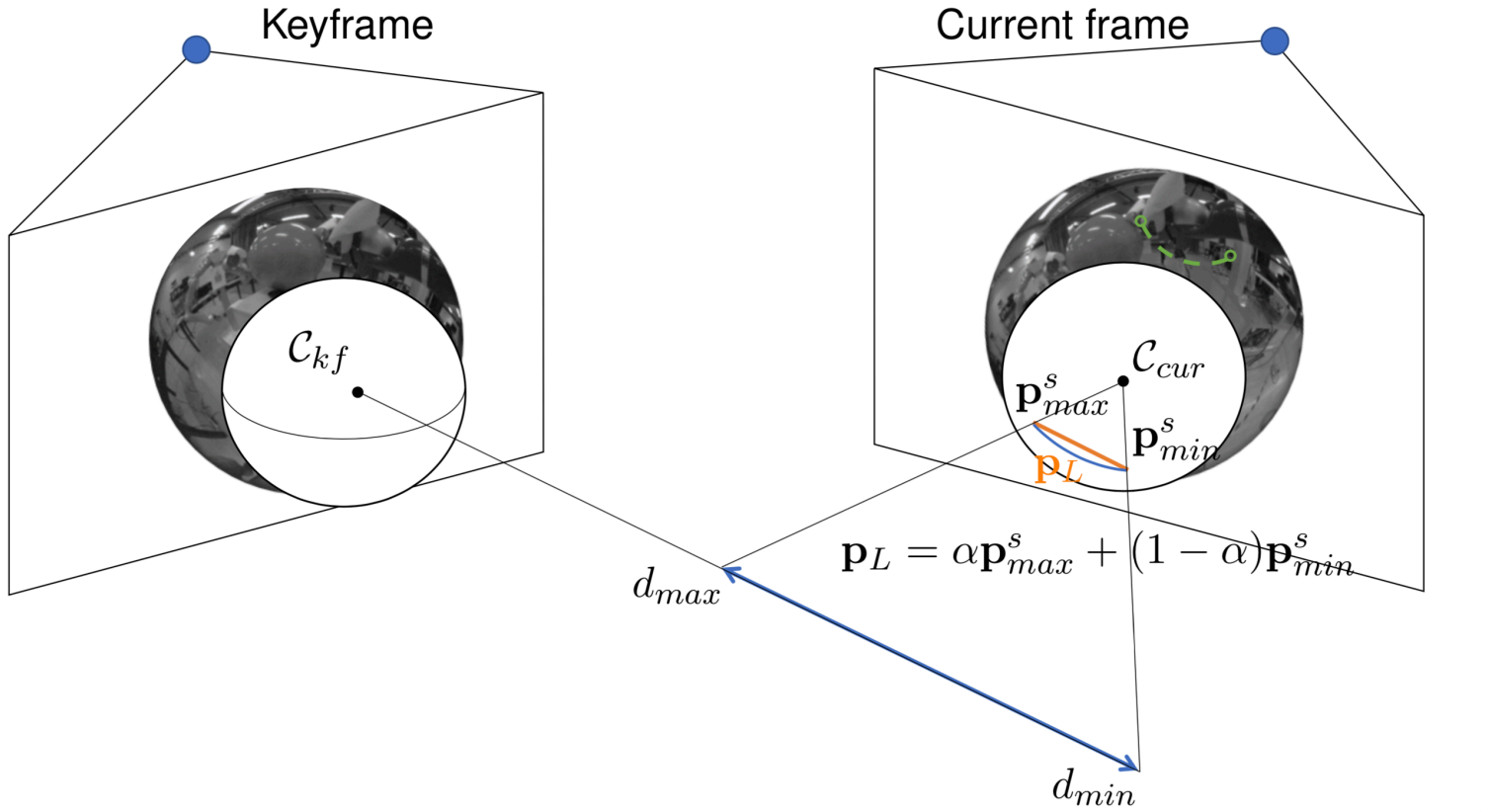
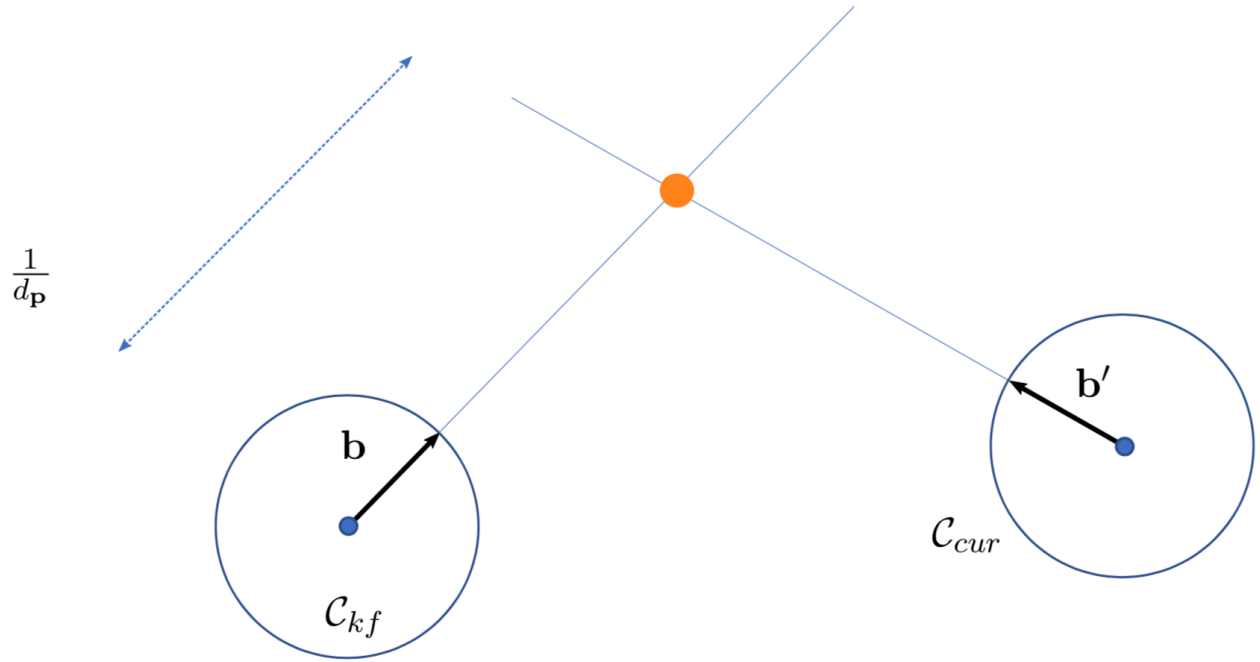


Figure based on that presented in OmniDSO

Approach

Candidate Point Tracking

Epipolar Curve Search



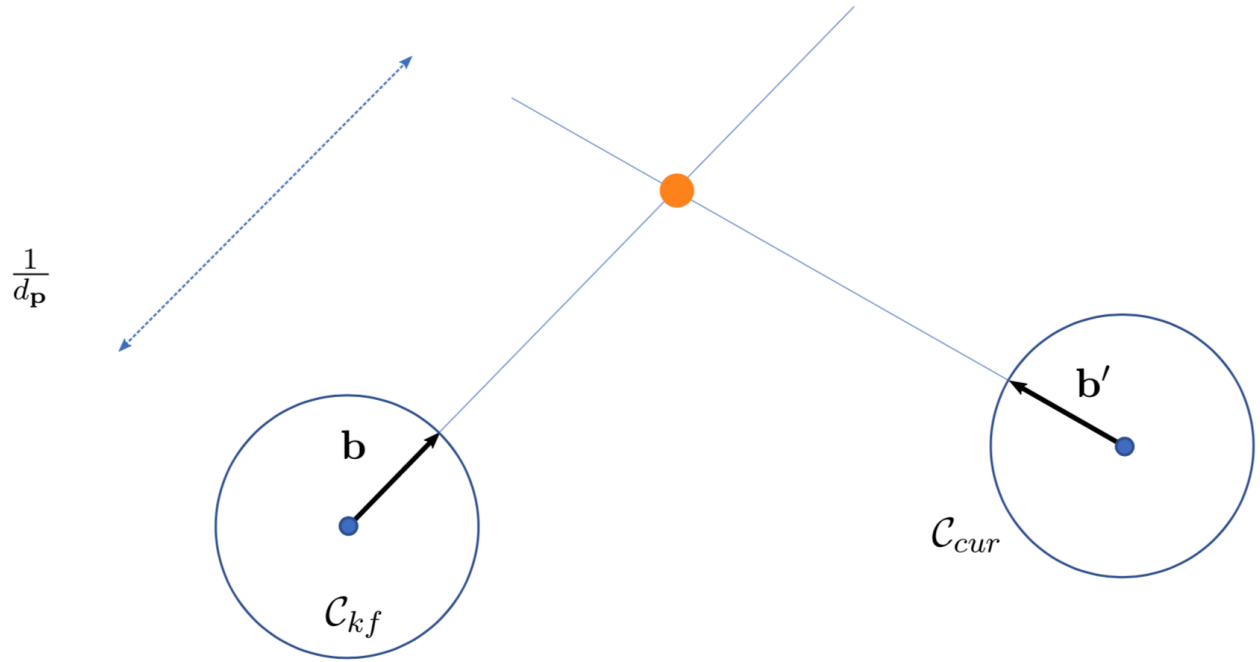
$$\begin{aligned}\mathbf{p}' &= \mathbf{R}\mathbf{p} + \mathbf{t} \\ &= \mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}\end{aligned}$$

$$\mathbf{b}' = \frac{\mathbf{p}'}{\|\mathbf{p}'\|} = \frac{\mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}}{\left\|\mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}\right\|}$$

Approach

Candidate Point Tracking

Epipolar Curve Search



$$\mathbf{p}' = \mathbf{R}\mathbf{p} + \mathbf{t}$$
$$= \mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}$$

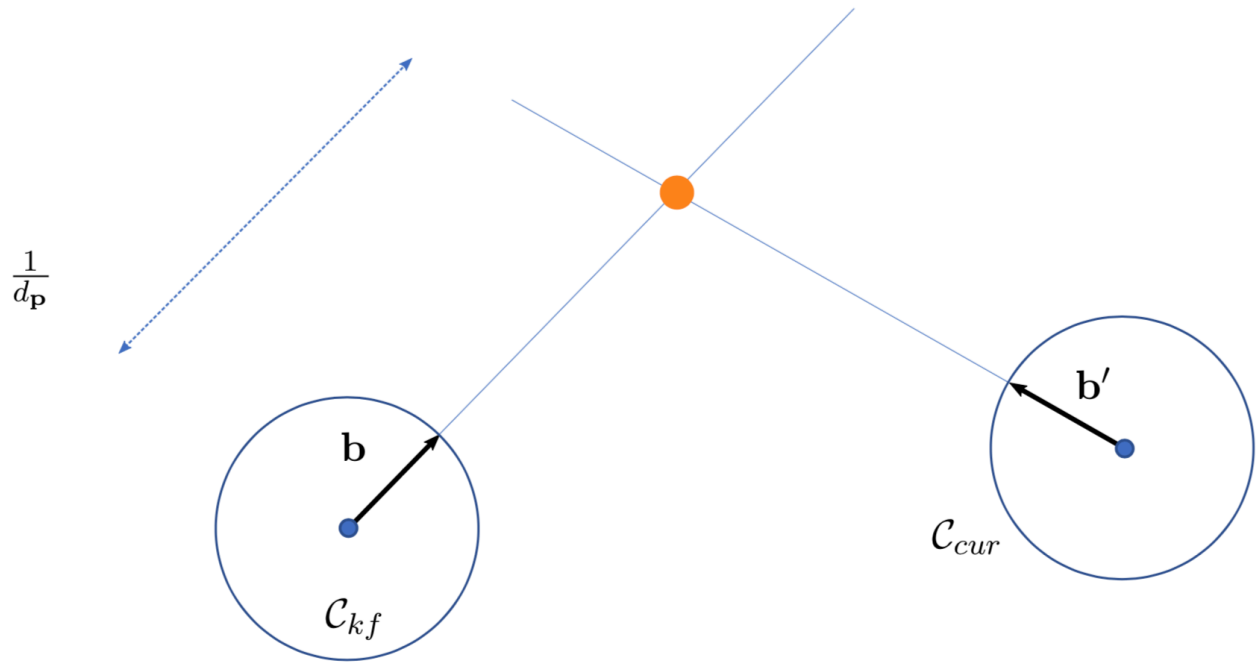
$$b'_x = \frac{p'_x}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_x}{\|\mathbf{p}'\|}$$

$$b'_y = \frac{p'_y}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_y}{\|\mathbf{p}'\|}$$

Approach

Candidate Point Tracking

Epipolar Curve Search



$$\mathbf{p}' = \mathbf{R}\mathbf{p} + \mathbf{t}$$
$$= \mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}$$

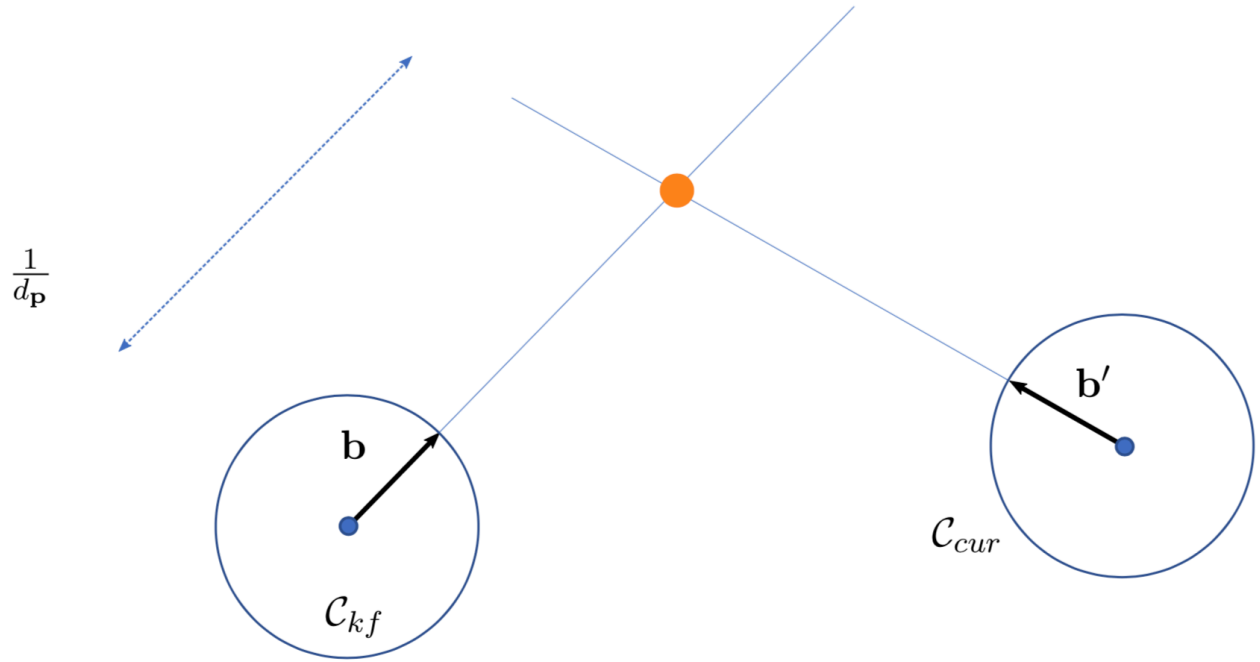
$$b'_x = \frac{p'_x}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_x}{\|\mathbf{p}'\|} \qquad b'_y = \frac{p'_y}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_y}{\|\mathbf{p}'\|}$$

$$\frac{b'_x}{b'_y} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_x}{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_y}$$

Approach

Candidate Point Tracking

Epipolar Curve Search

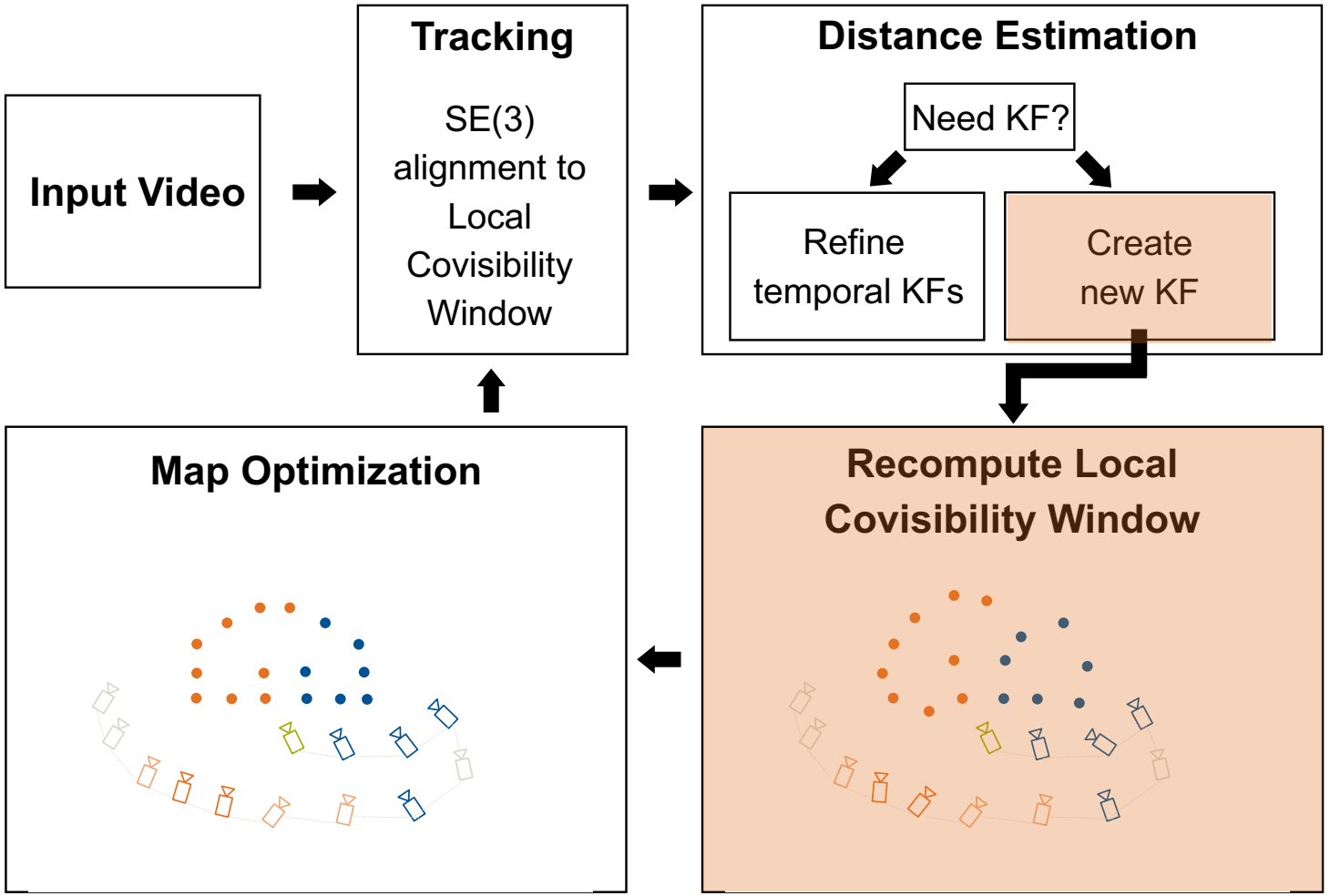


$$\mathbf{p}' = \mathbf{R}\mathbf{p} + \mathbf{t}$$
$$= \mathbf{R}\frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}$$

$$d_{\mathbf{p}} = \frac{b'_y \mathbf{r}_0 \cdot \mathbf{b} - b'_x \mathbf{r}_1 \cdot \mathbf{b}}{b'_x t_y - b'_y t_x}$$

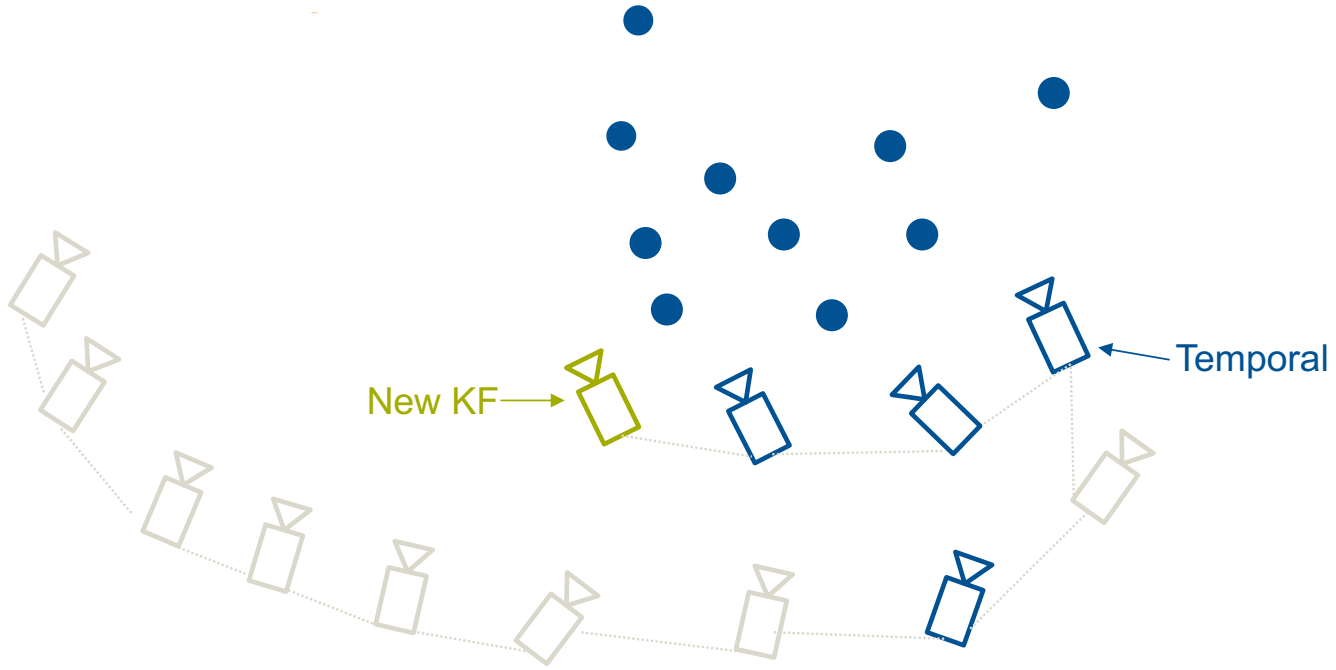
Approach

Overview



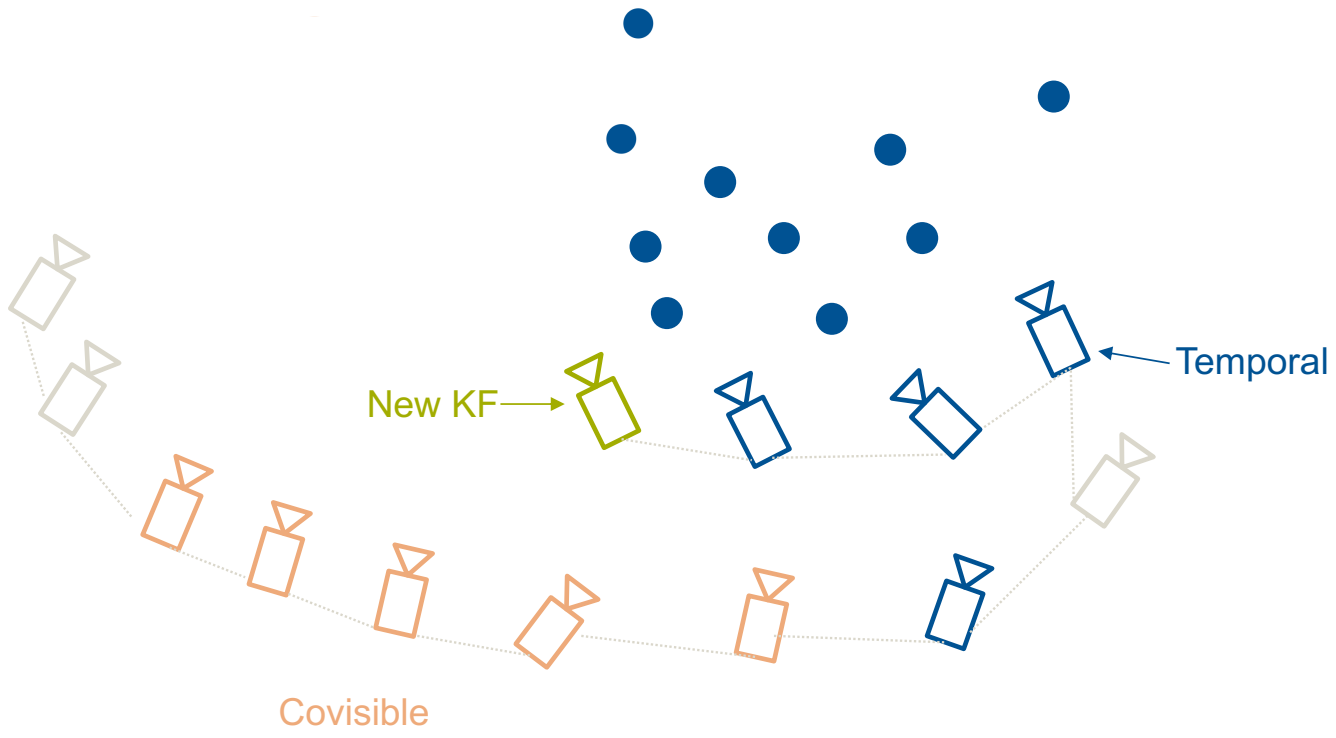
Approach

Recomputing Local Covisibility Window



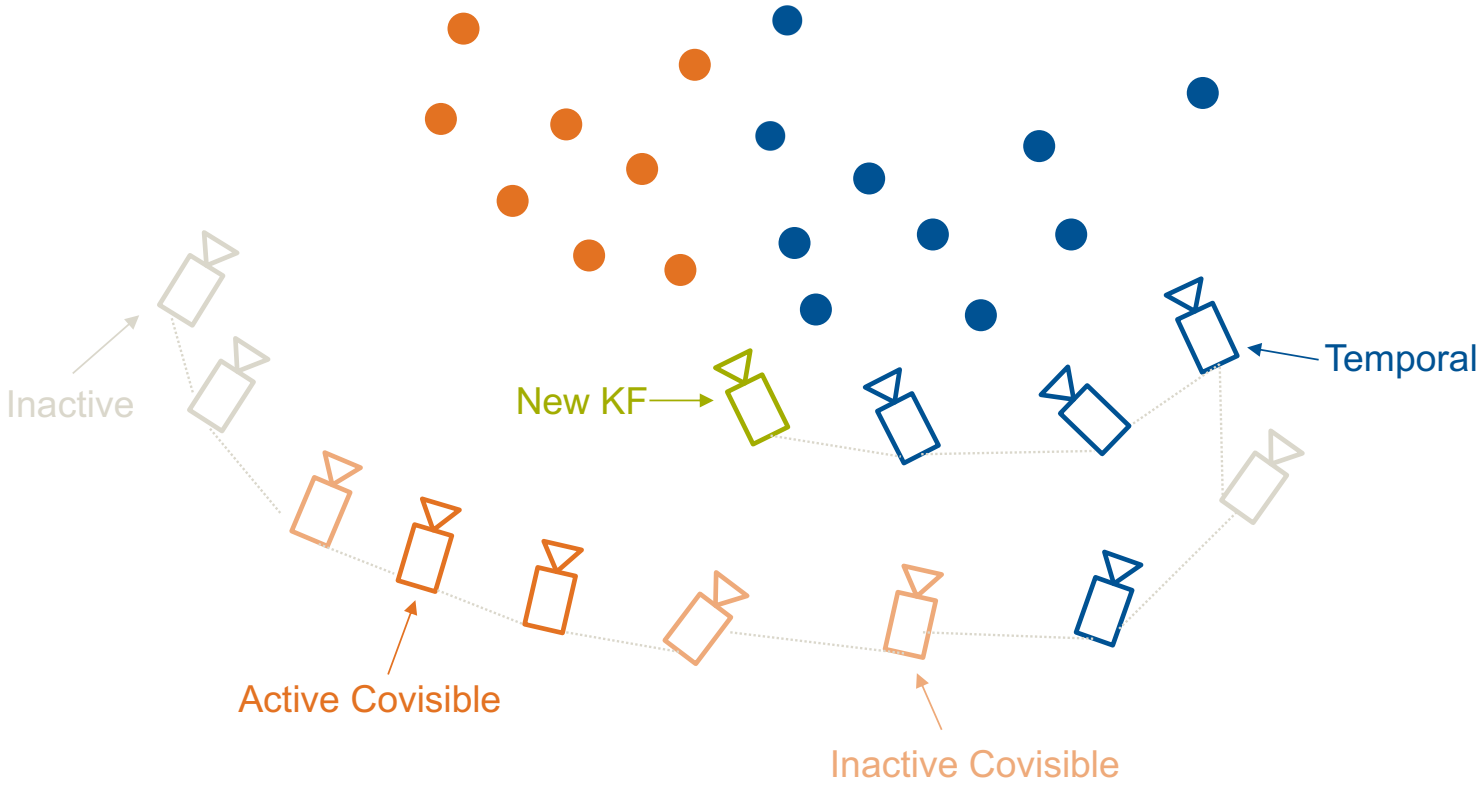
Approach

Recomputing Local Covisibility Window



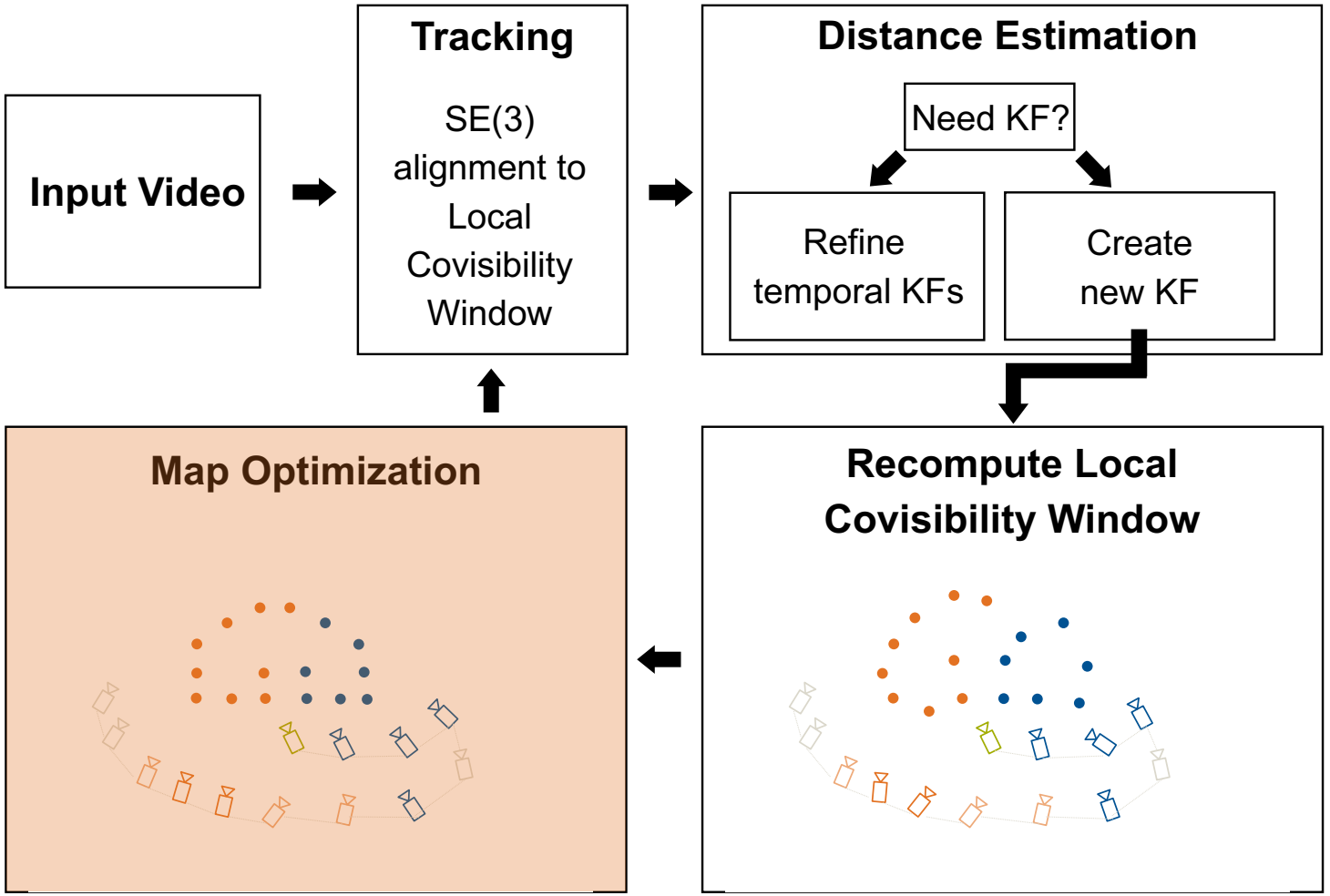
Approach

Recomputing Local Covisibility Window



Approach

Overview



Approach

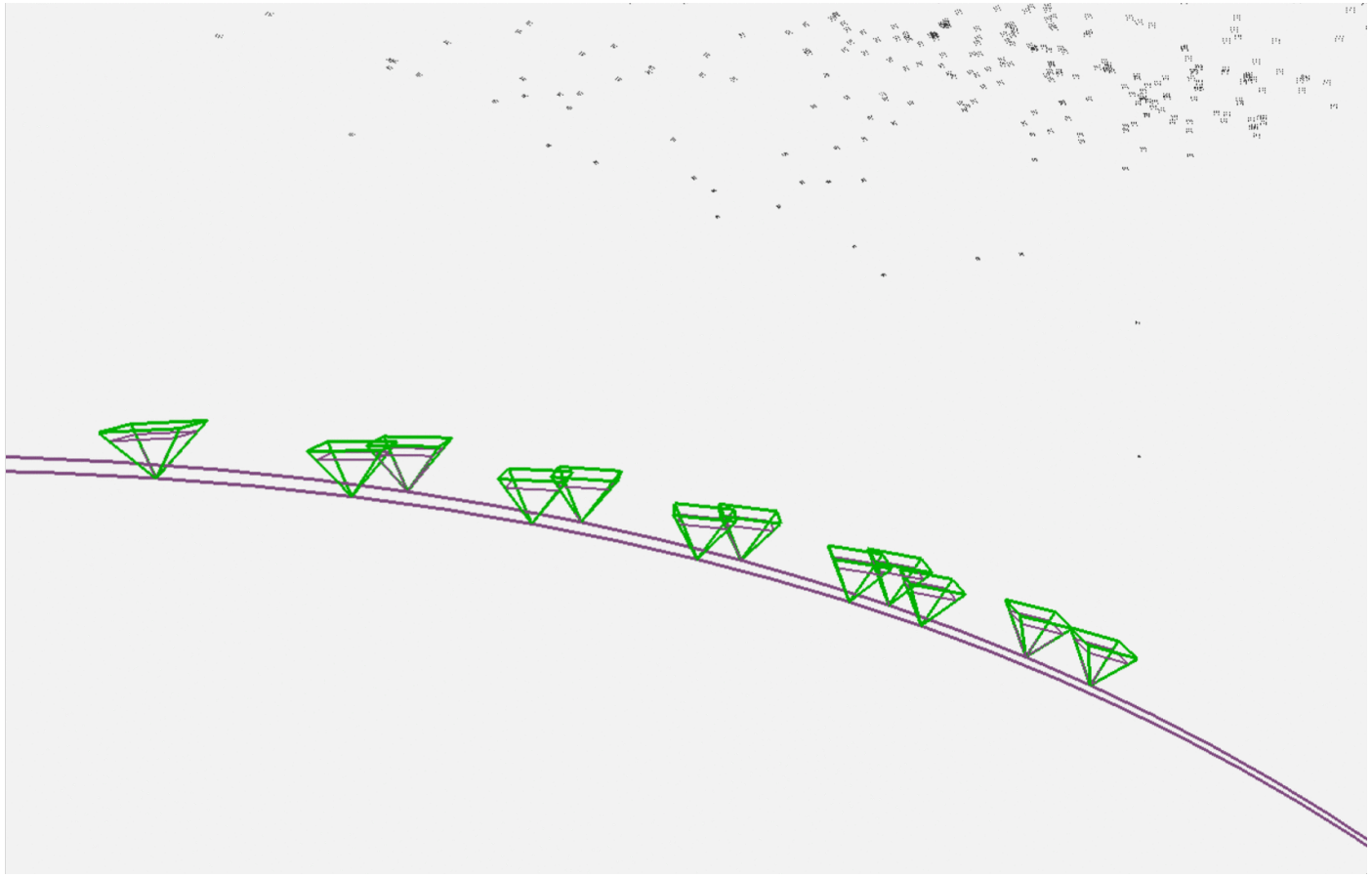
Photometric Bundle Adjustment

- Ceres

(w/o coarse-to-fine)

- Manual Solver

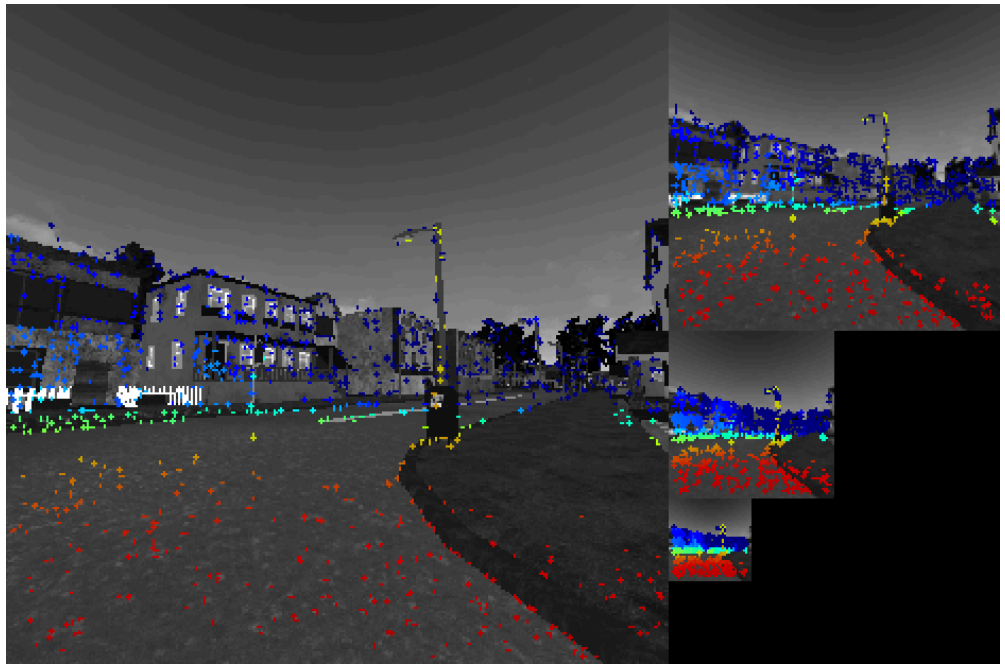
(w/ and w/o coarse-to-fine)



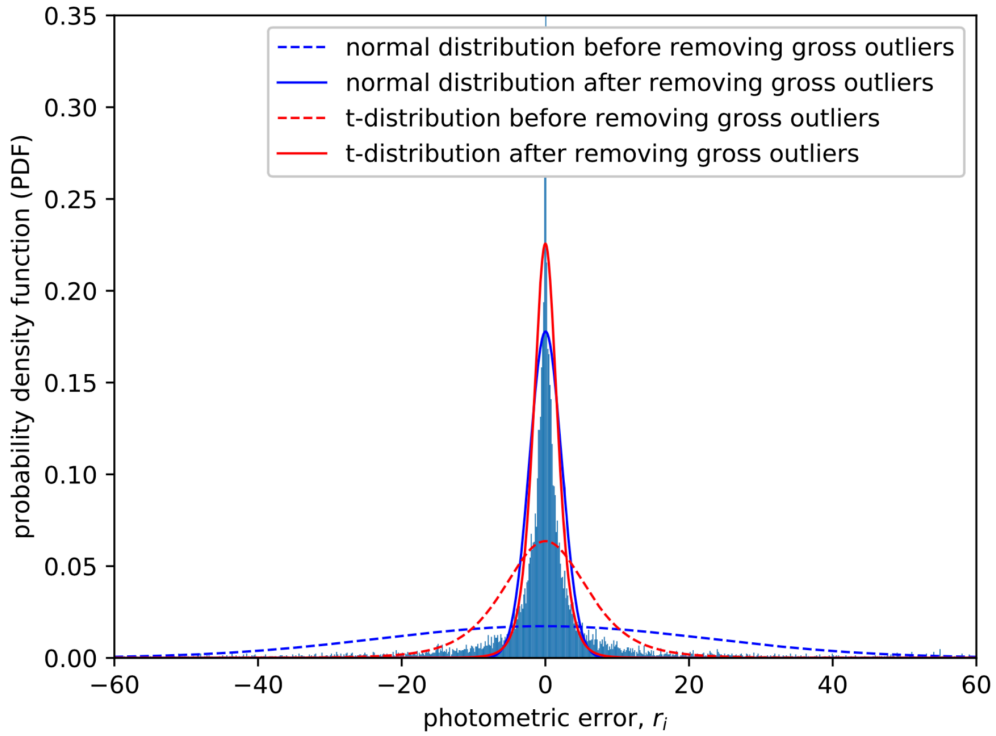
Approach

Robustification

Coarse-to-Fine



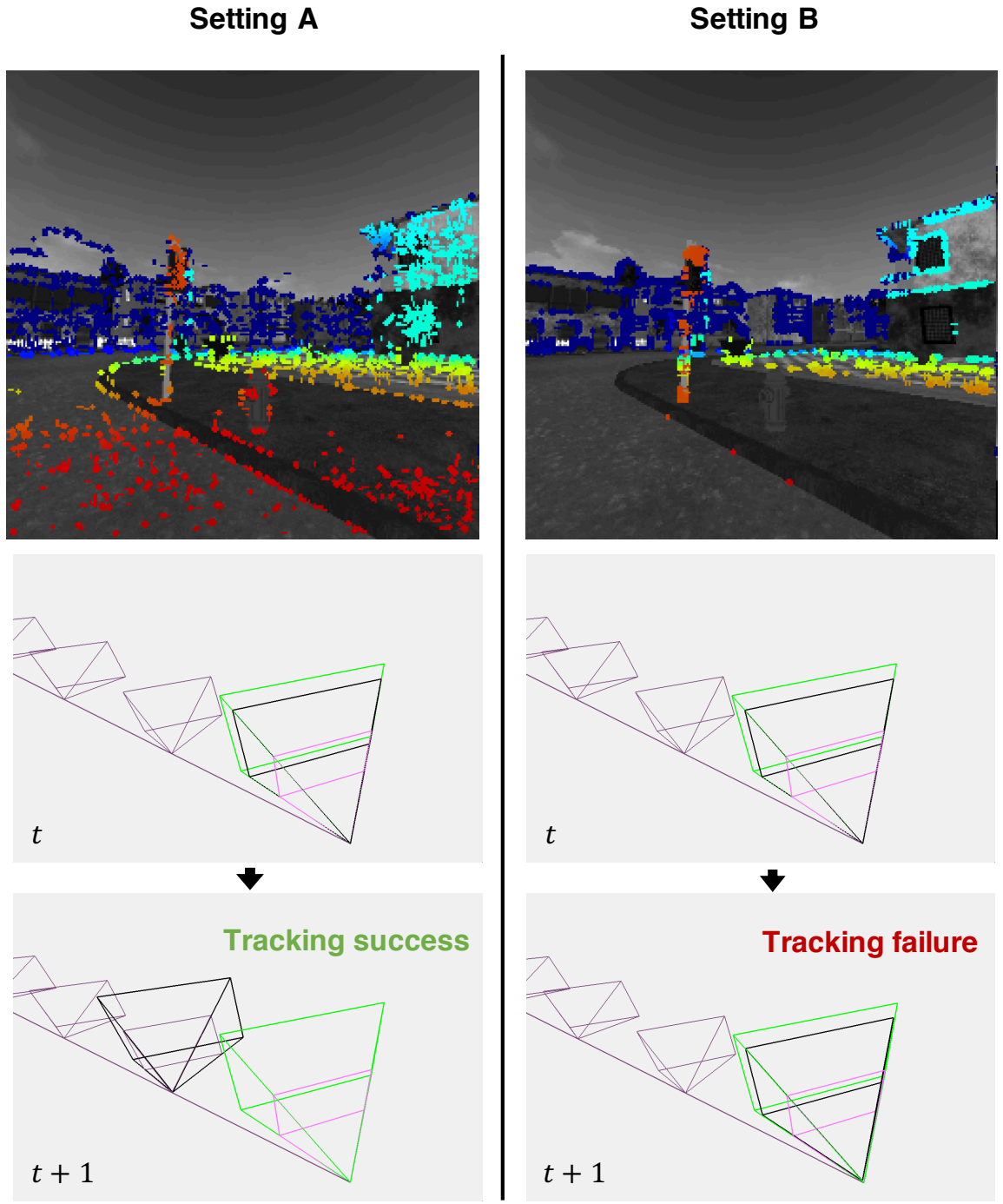
Residual Distribution



Results

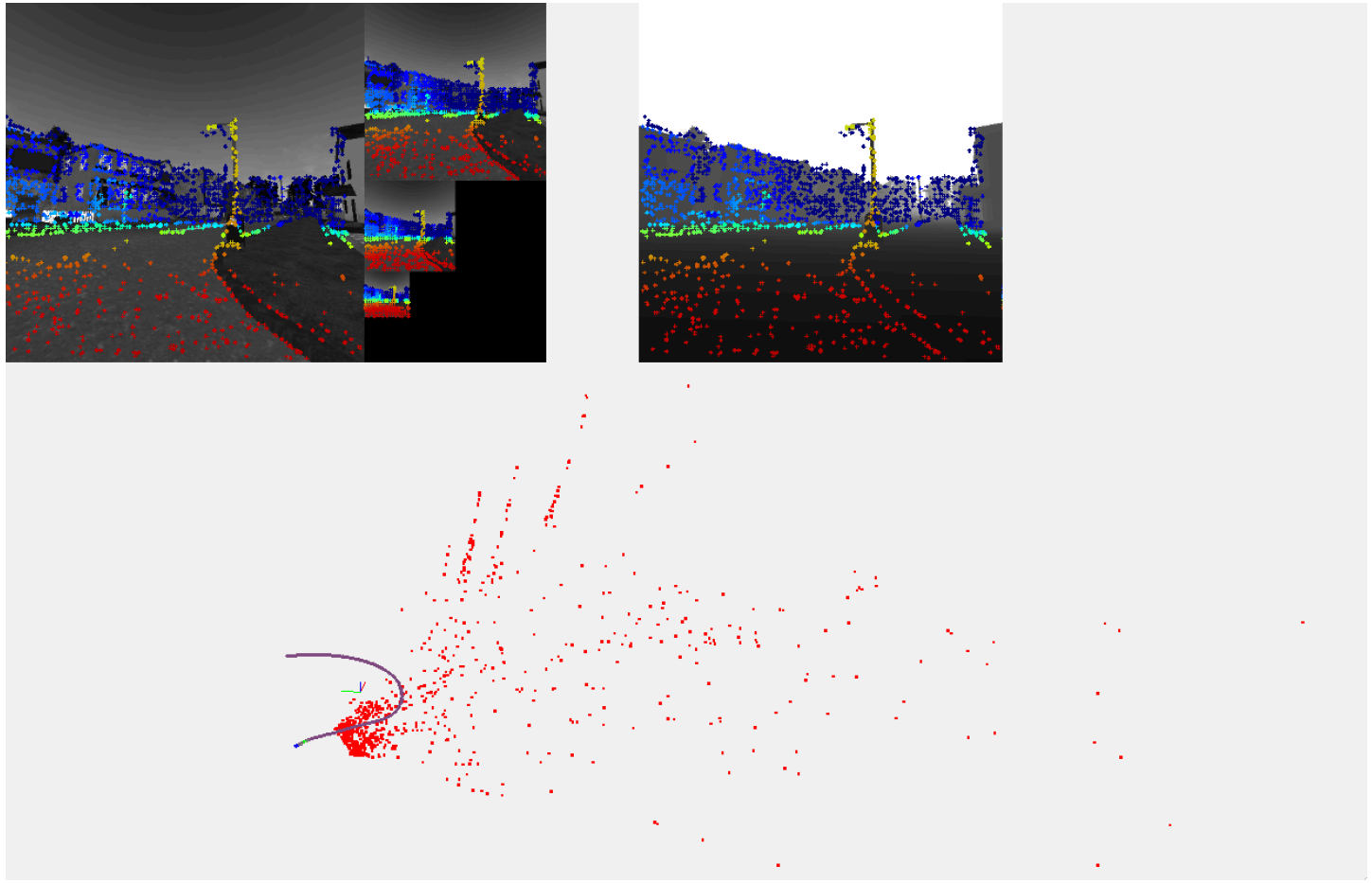
Results

Influence of Candidate Point Selection on Tracking



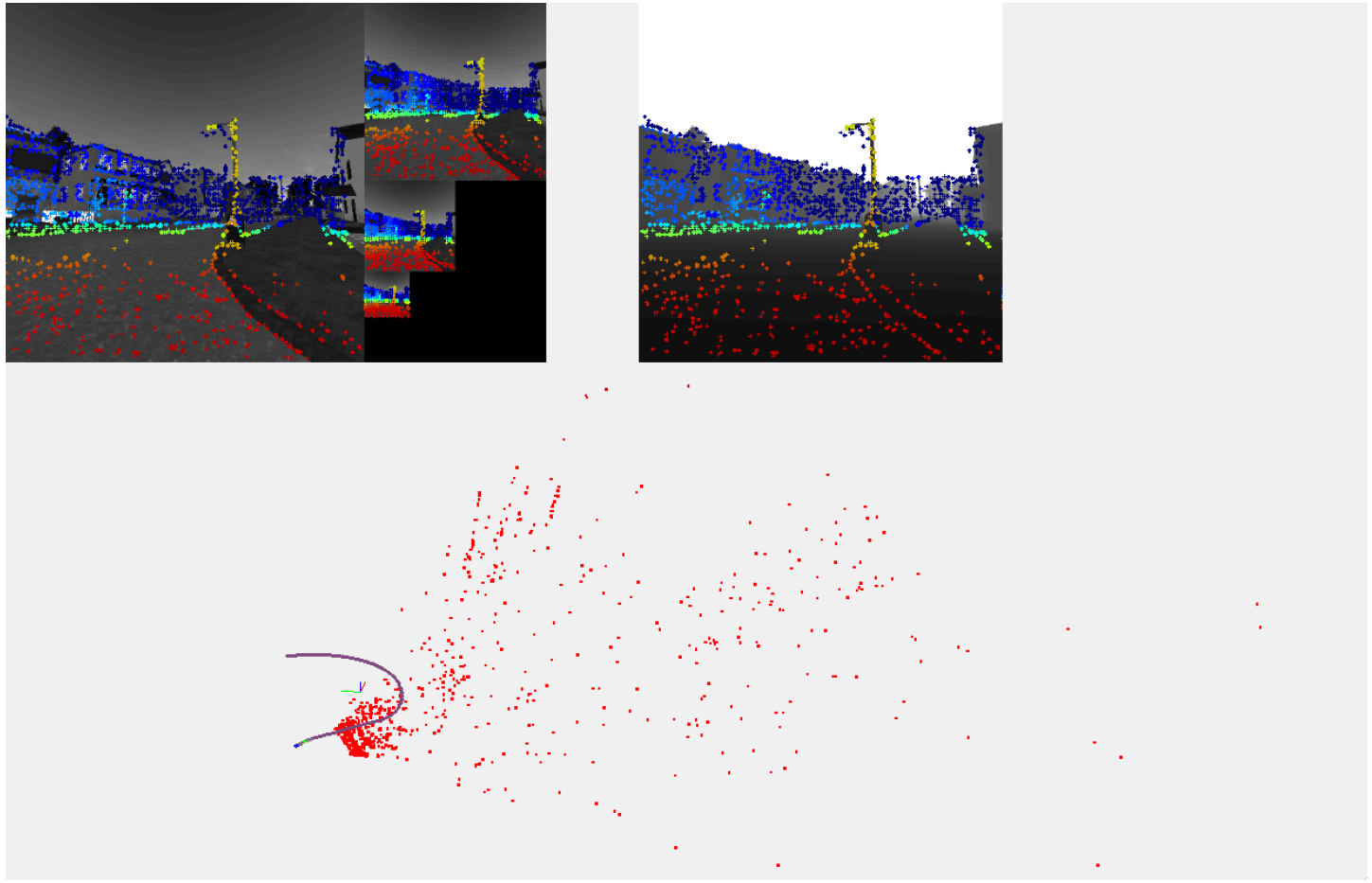
Results

Candidate Point Tracking



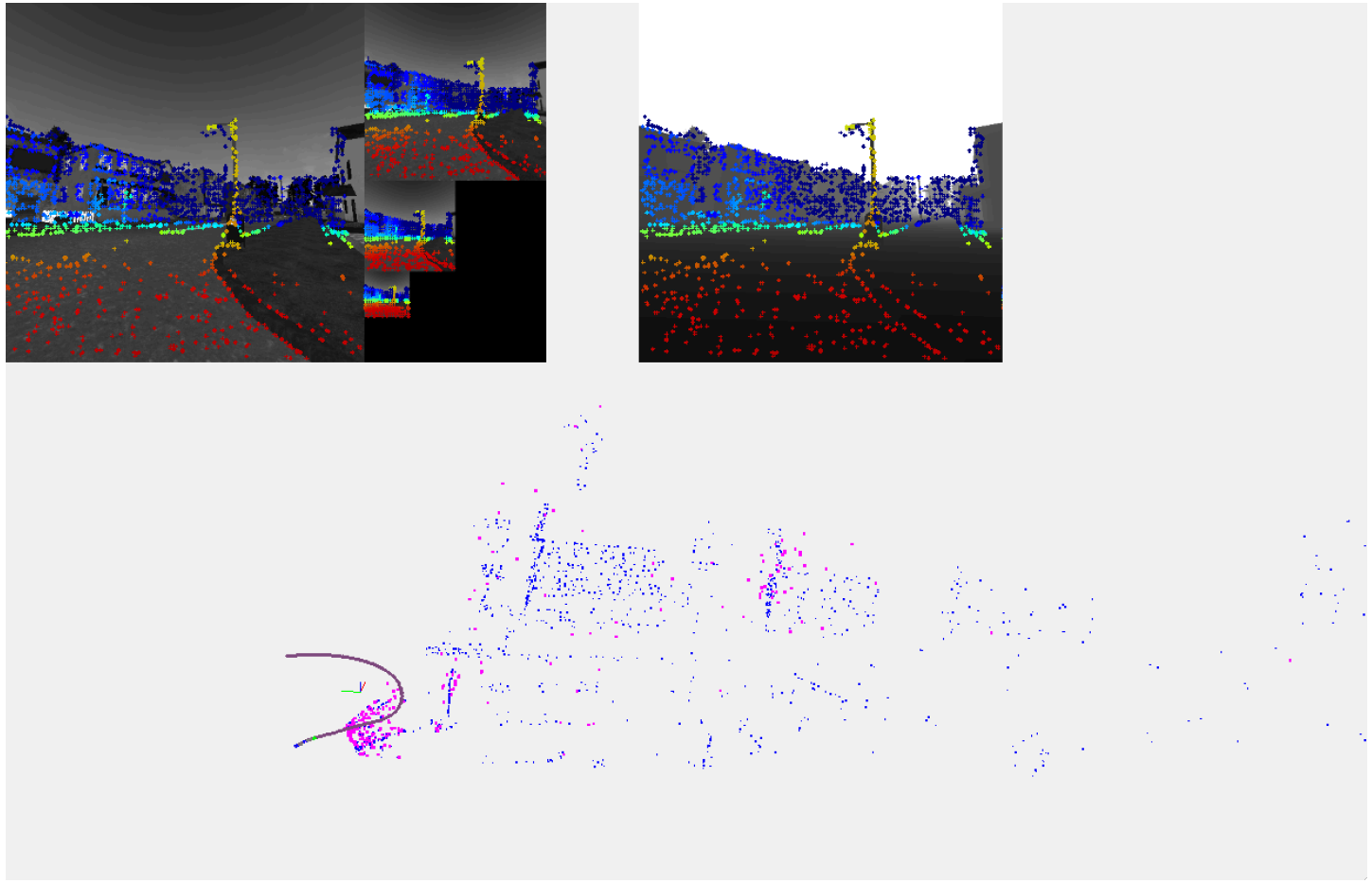
Results

Candidate Point Tracking



Results

Candidate Point Tracking

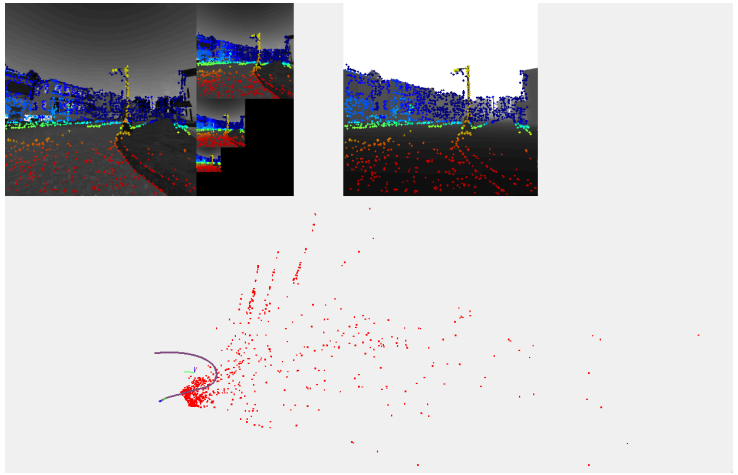


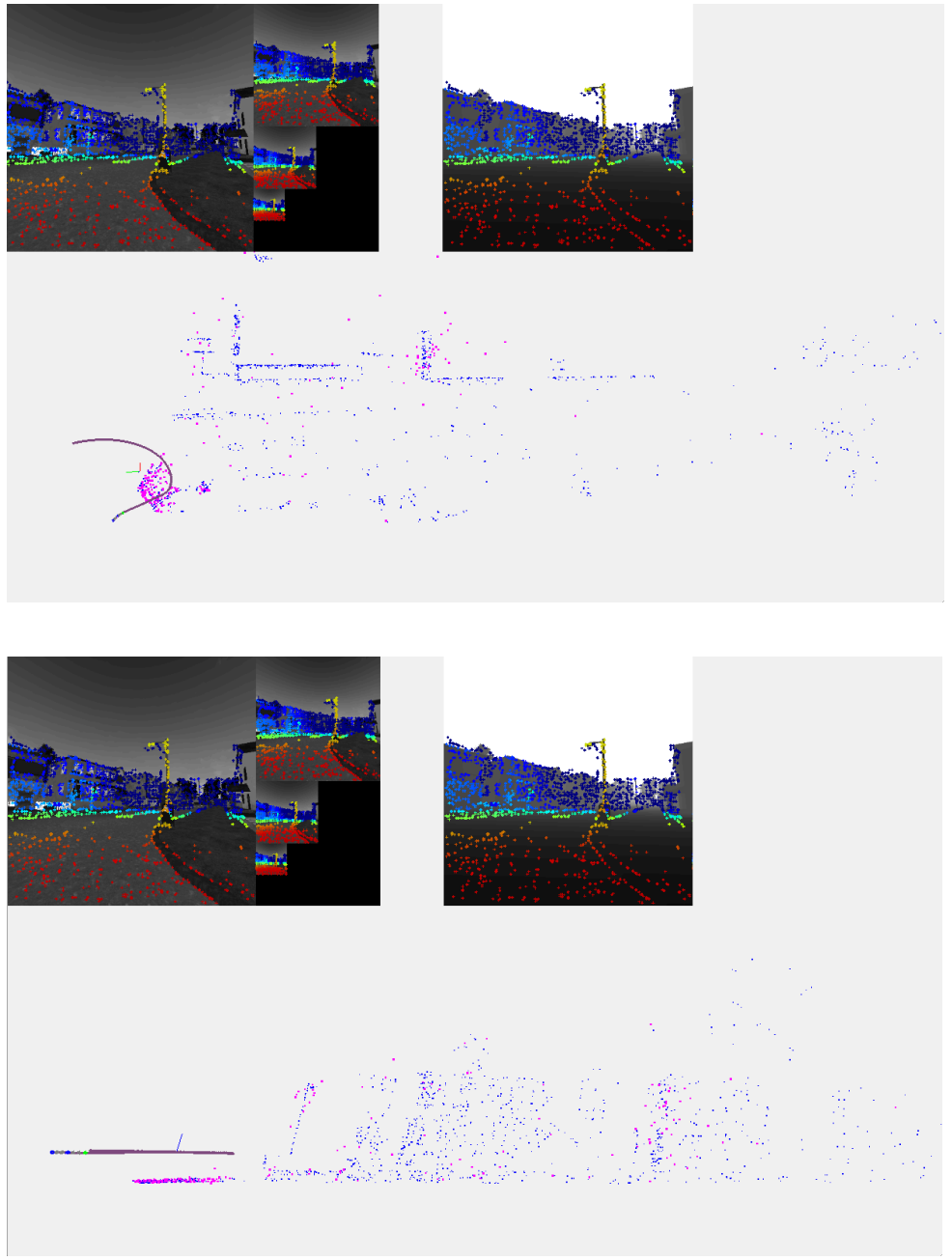
Upgraded to Landmarks

Results

Candidate

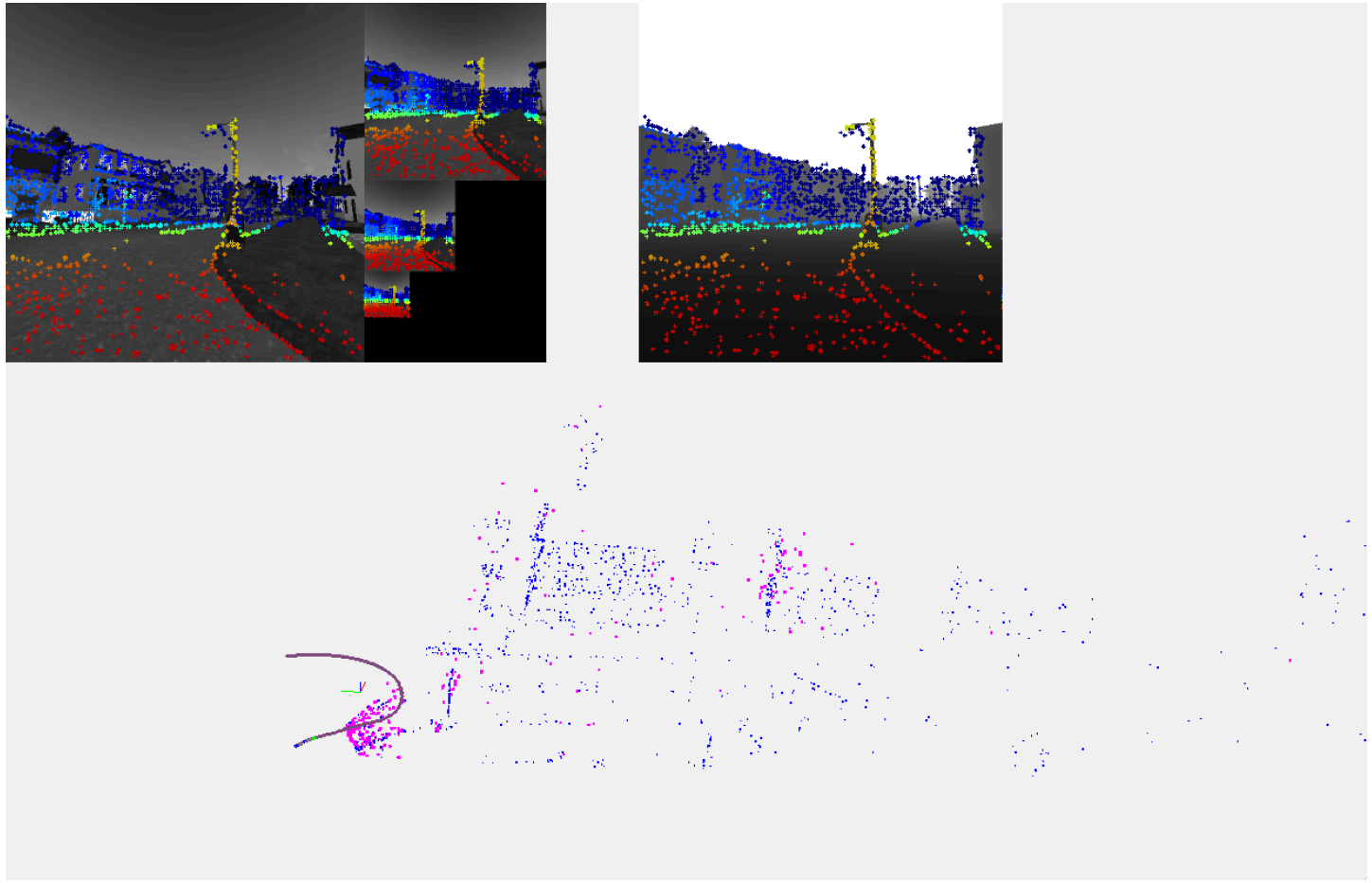
Point Tracking





Results

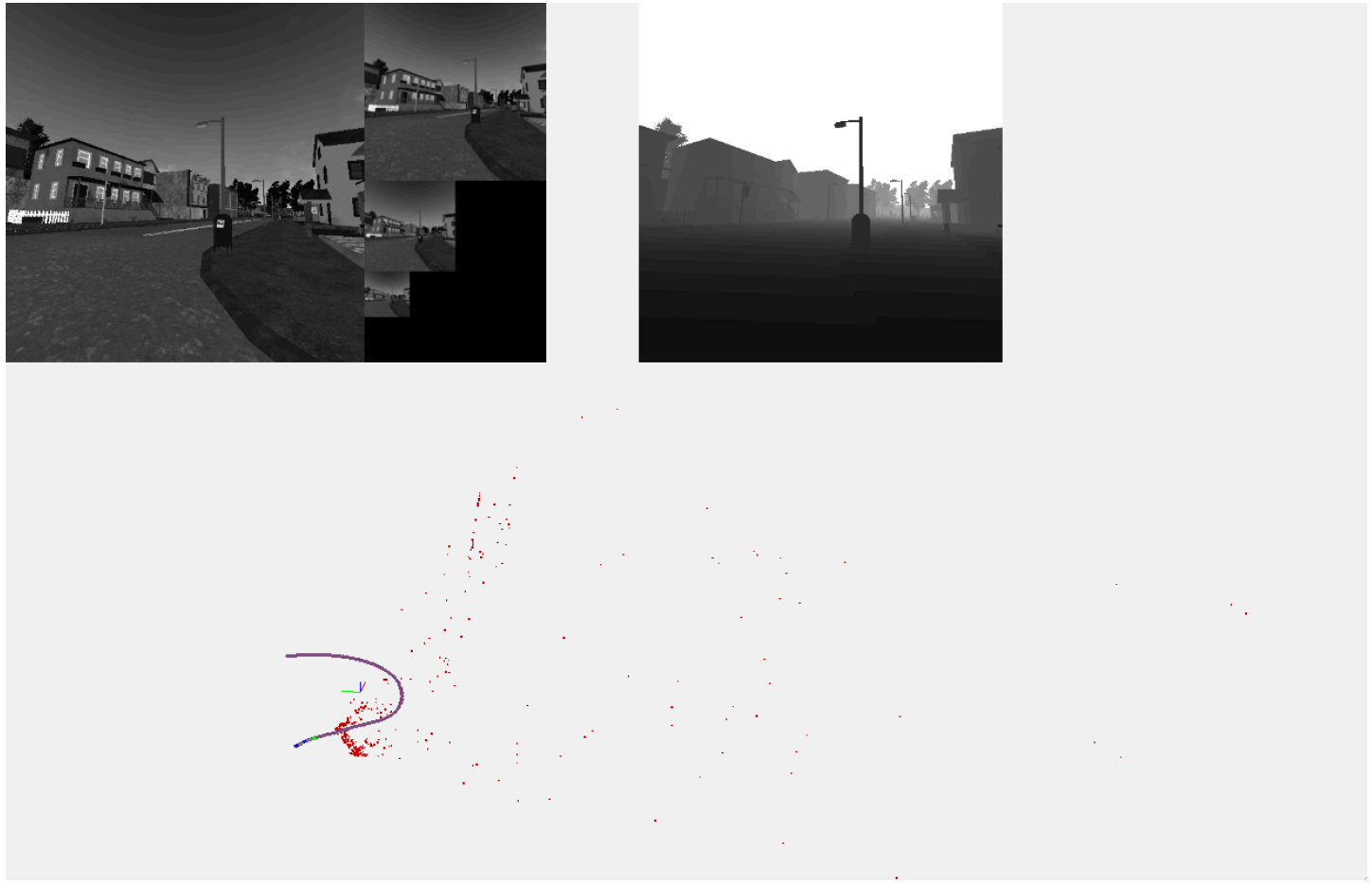
Candidate Point Tracking



Upgraded to Landmarks

Results

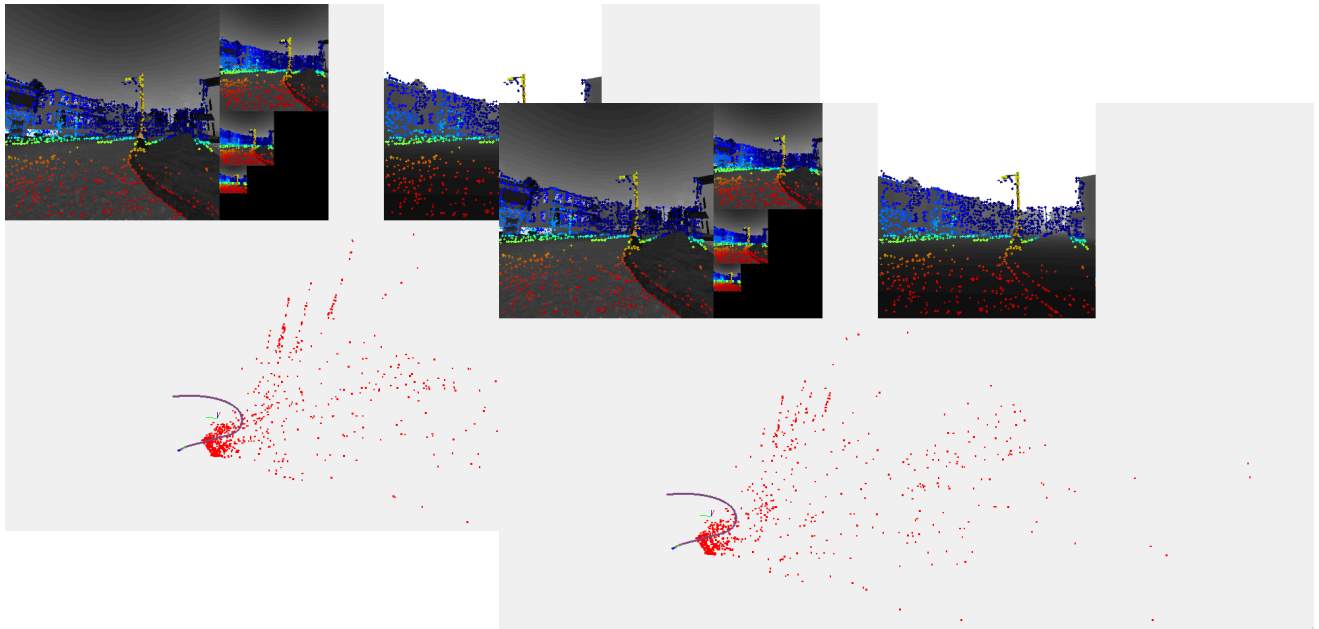
Candidate Point Tracking

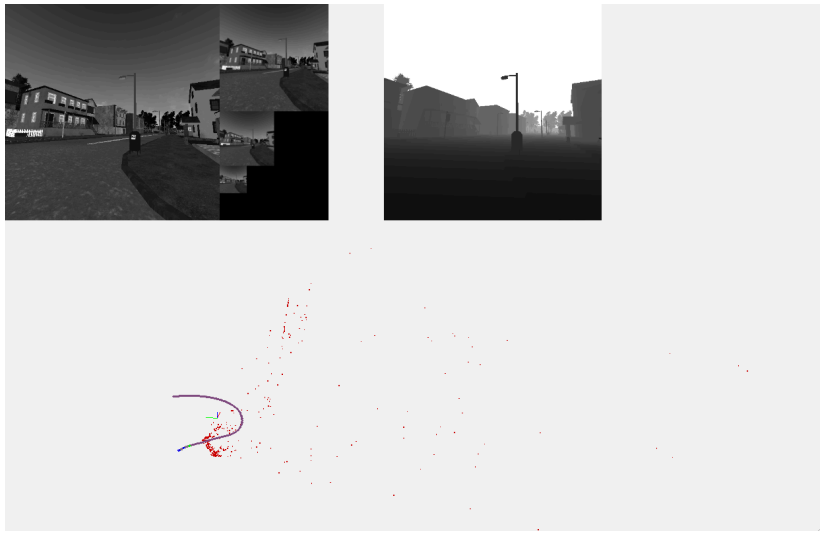


Remaining as Candidate Points

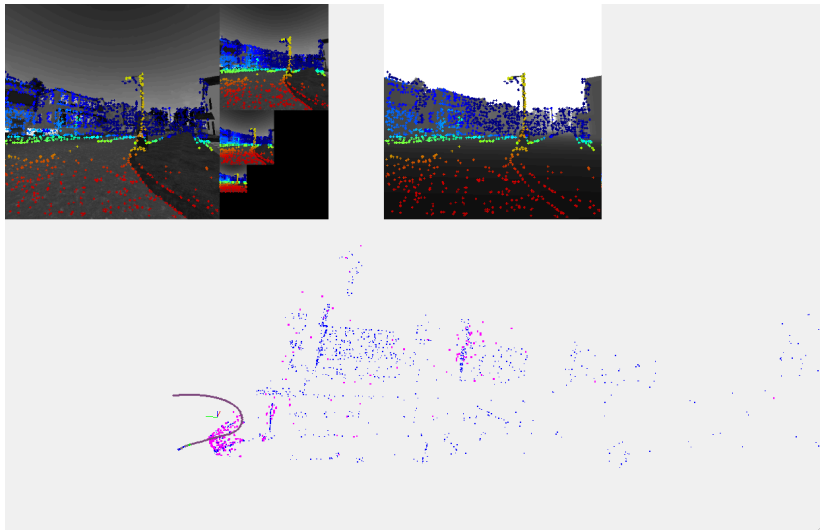
Results

Candidate Point Tracking





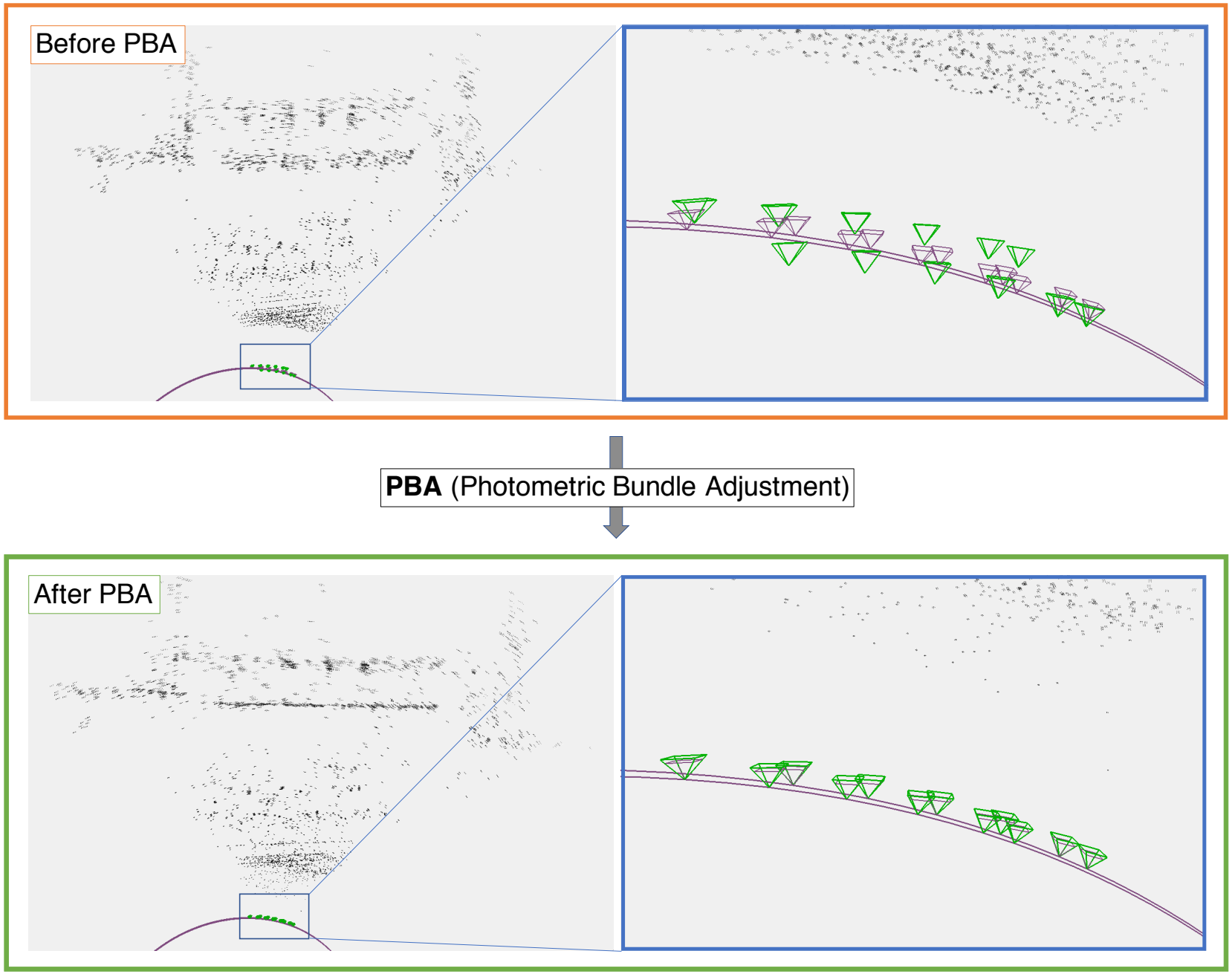
Remaining as Candidate Points



Upgraded to Landmarks

Results

Photometric Bundle Adjustment



Results

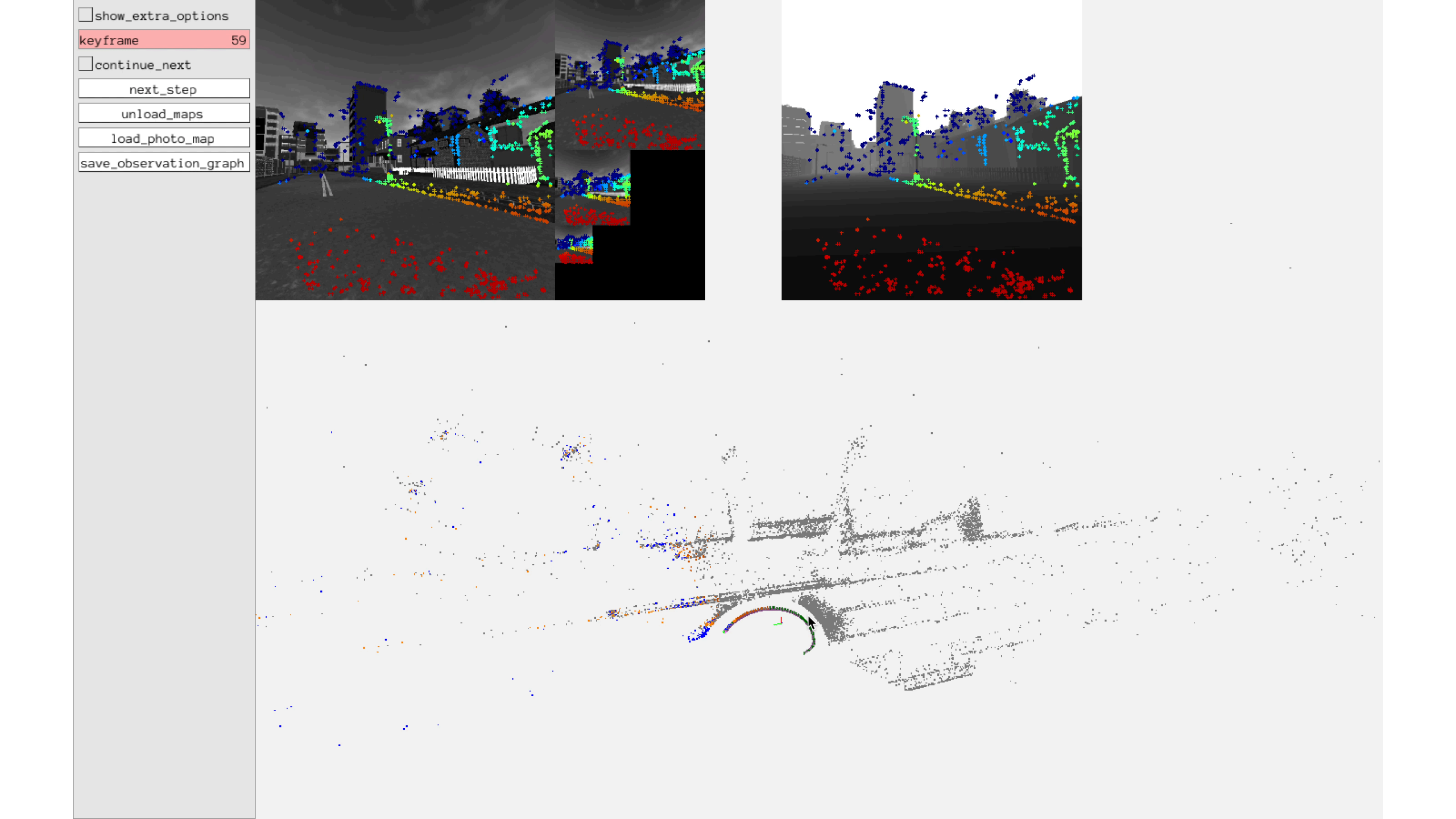
Photometric Bundle Adjustment

Max Number of Iterations per Level: **10**

Solver Type		Metric						
		ATE (m)	Runtime (s)	Iterations				
				Total	Level			
					3	2	1	0
Manual	w/o pyrs	0.00131	0.43	10	-	-	-	10
Ceres	w/o pyrs	0.03761	2.05	10	-	-	-	10
Manual	w/ pyrs	0.00054	2.42	29	7	3	10	9
Ceres	w/ pyrs	-	-	-	-	-	-	-

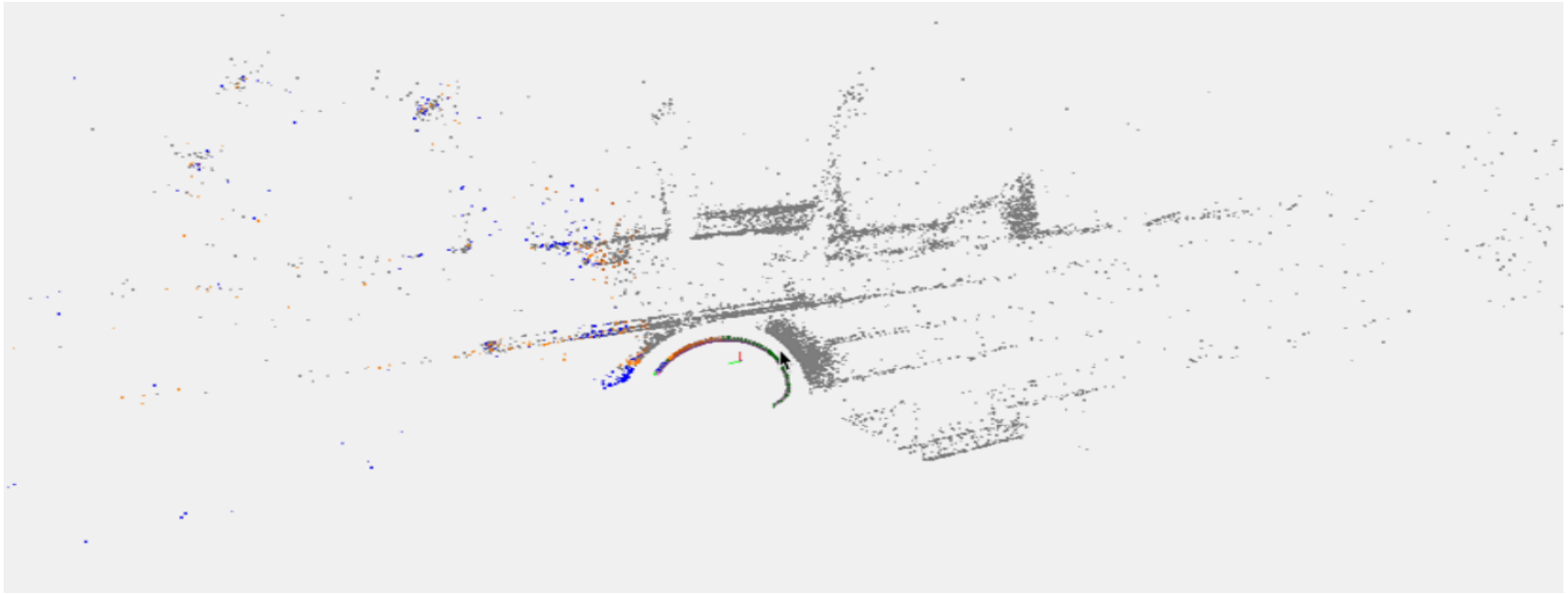
Results

Full System

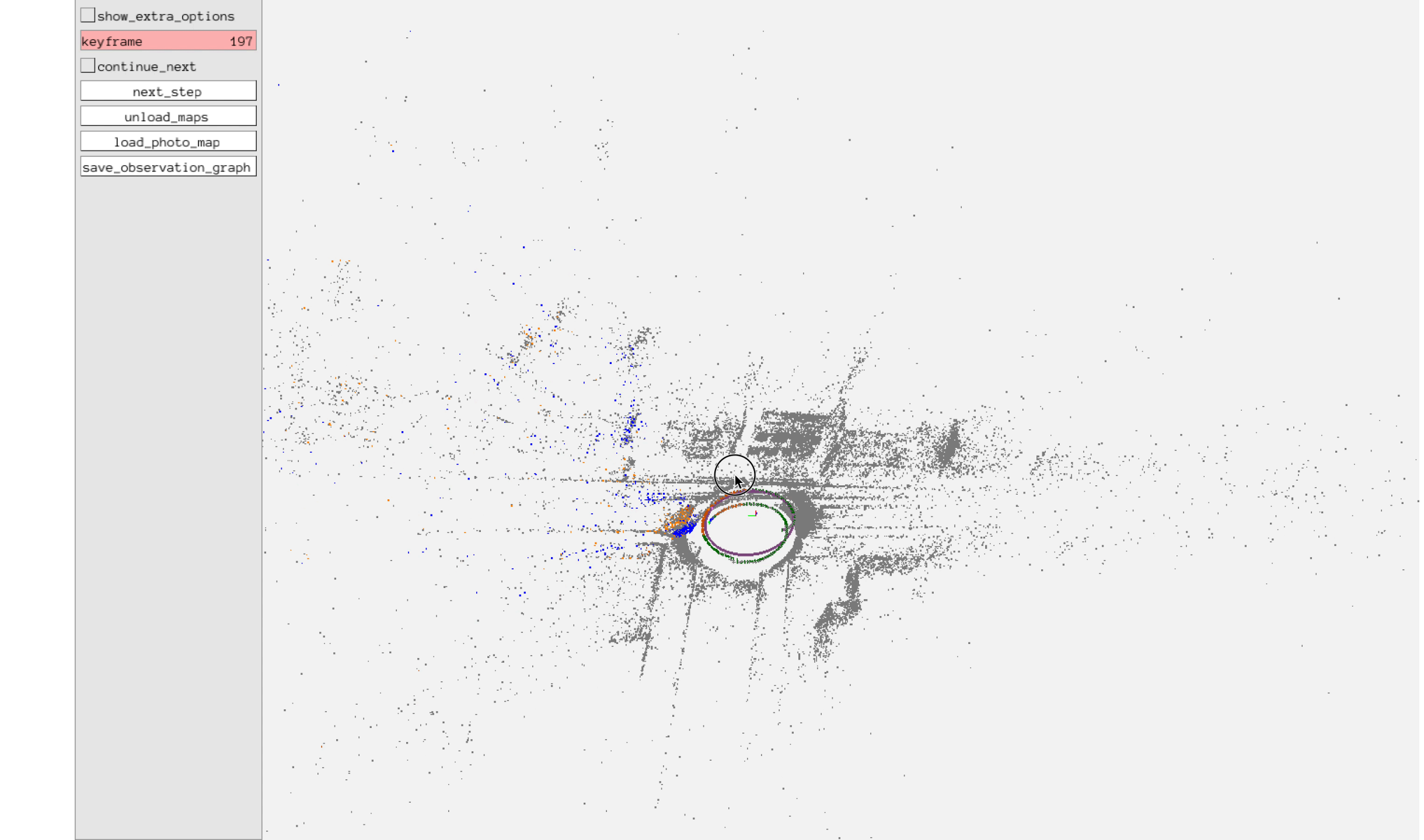

show_extra_options
keyframe 59
continue_next
next_step
unload_maps
load_photo_map
save_observation_graph

Results

Full System

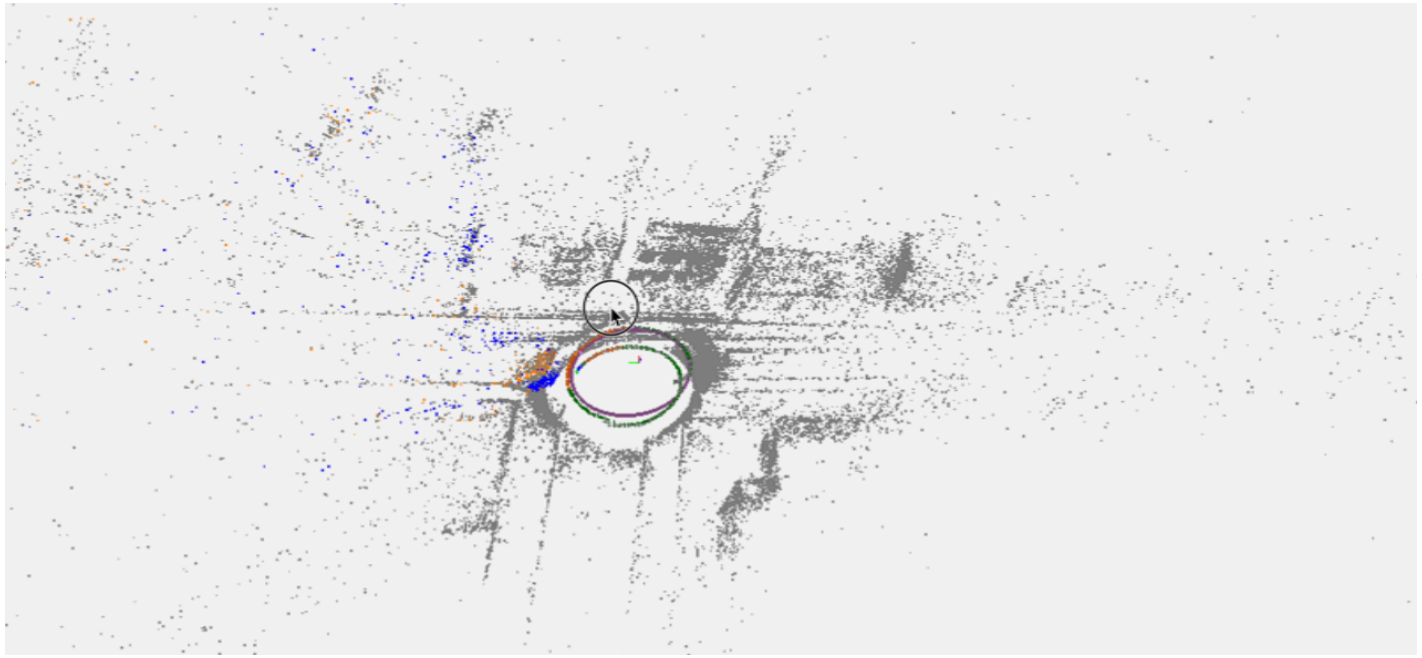


RMSE ATE: **0.00589** m


show_extra_options
keyframe 197
continue_next
next_step
unload_maps
load_photo_map
save_observation_graph

Results

Full System



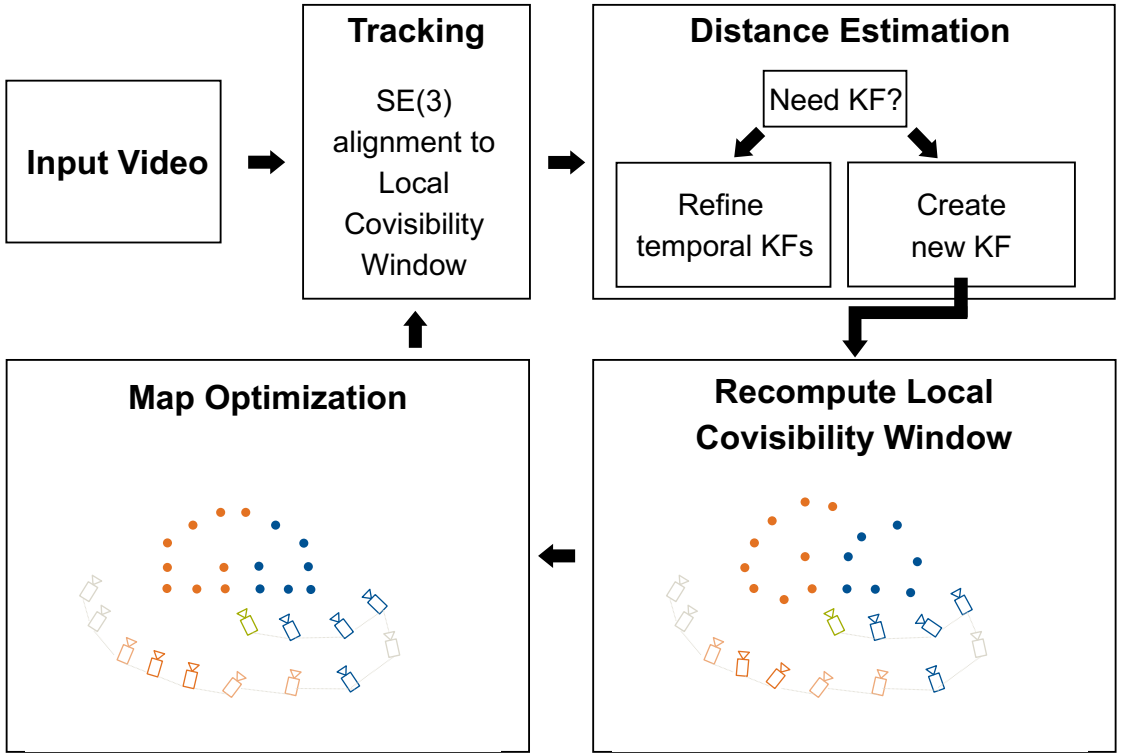
RMSE ATE: **1.05** m

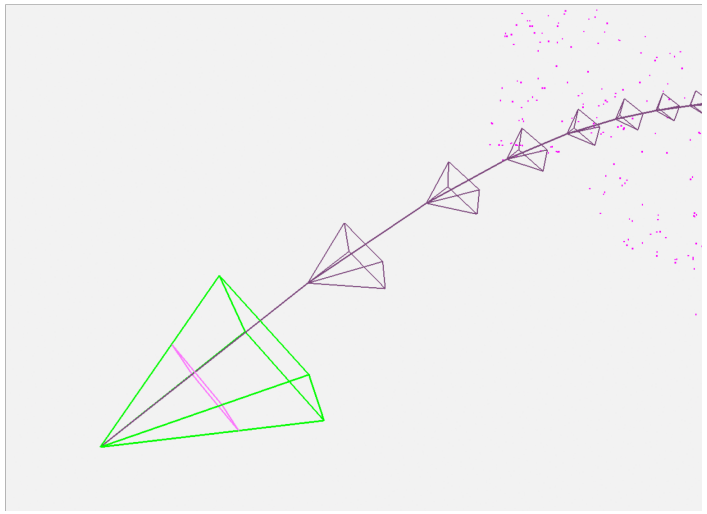
Conclusion

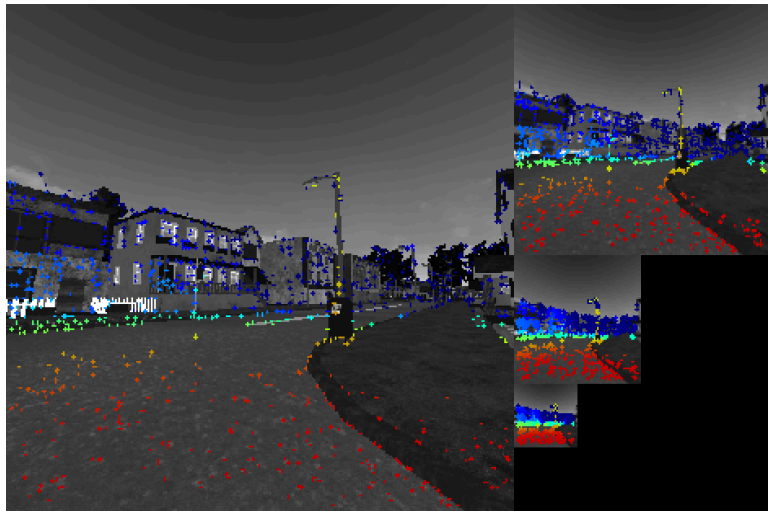
Direct **SLAM**

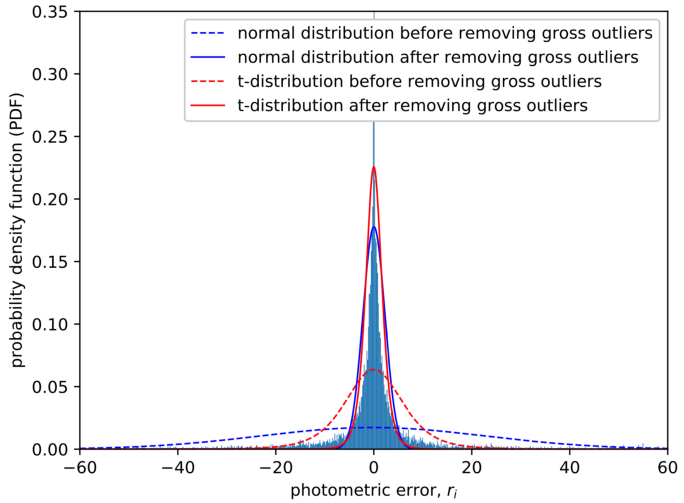
+

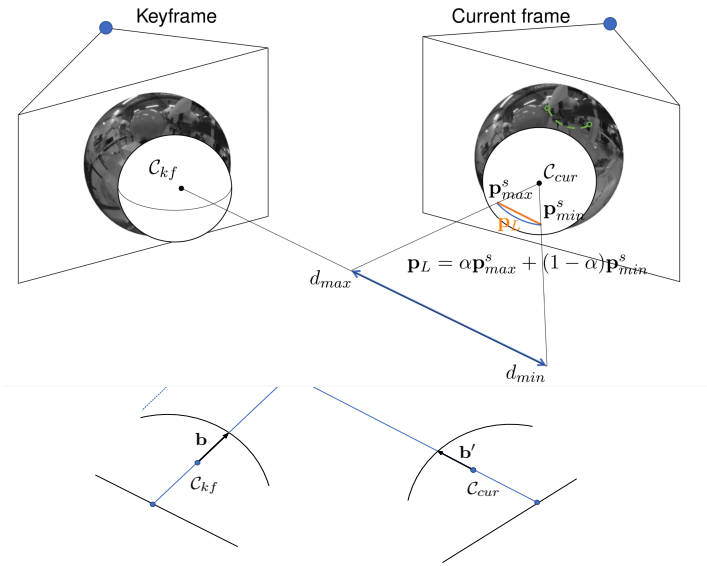
Modular & flexible **framework** for future development

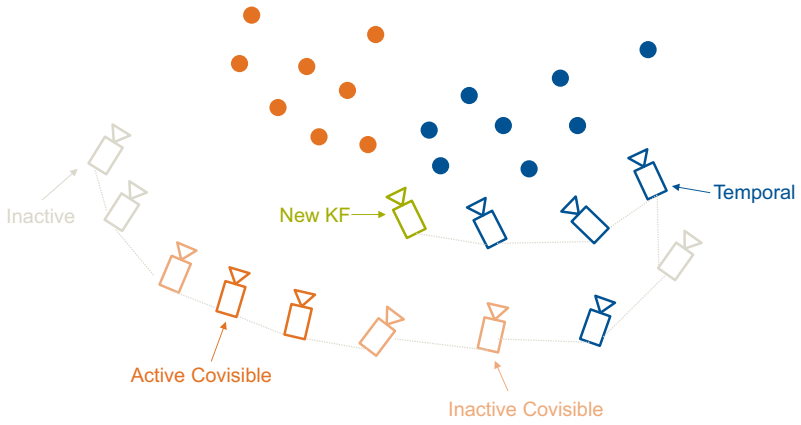


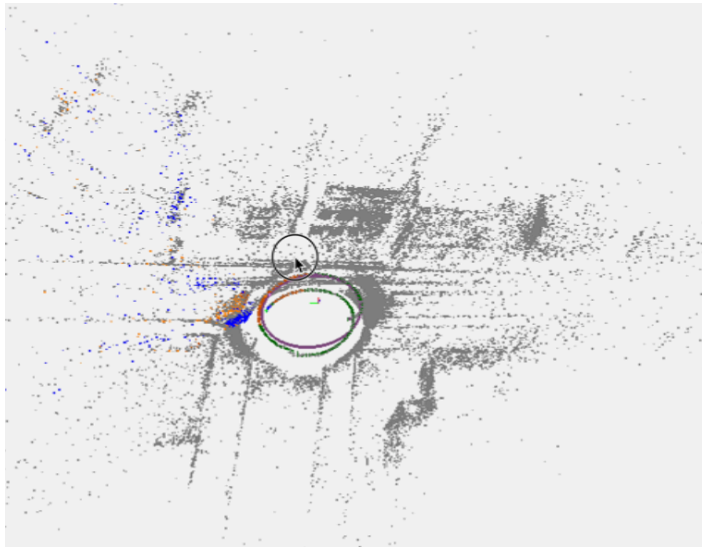





normal distribution before removing gross outliers
normal distribution after removing gross outliers
t-distribution before removing gross outliers
t-distribution after removing gross outliers
probability density function (PDF)
photometric error, r_i
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−60
−40
−20
0
20
40
60


Keyframe
Current frame
$\mathcal{C}_{kf}$
$\mathcal{C}_{cur}$
$\mathbf{p}^s_{max}$
$\mathbf{p}^s_{min}$
$\mathbf{p}_L$
$\mathbf{p}_L = \alpha \mathbf{p}^s_{max} + (1-\alpha)\mathbf{p}^s_{min}$
d_{max}
d_{min}
$\mathbf{b}$
$\mathbf{b}'$
$\mathcal{C}_{kf}$
$\mathcal{C}_{cur}$


Inactive
New KF
Temporal
Active Covisible
Inactive Covisible



Future Work

- Refine system and find good balance for user-defined parameters
- Pose-graph optimization to close larger loops:

  Double-window optimization (accurate pose-point & soft pose-pose)
- Test the system on real datasets (e.g., EuRoC)

Thank you very much for your attention.

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