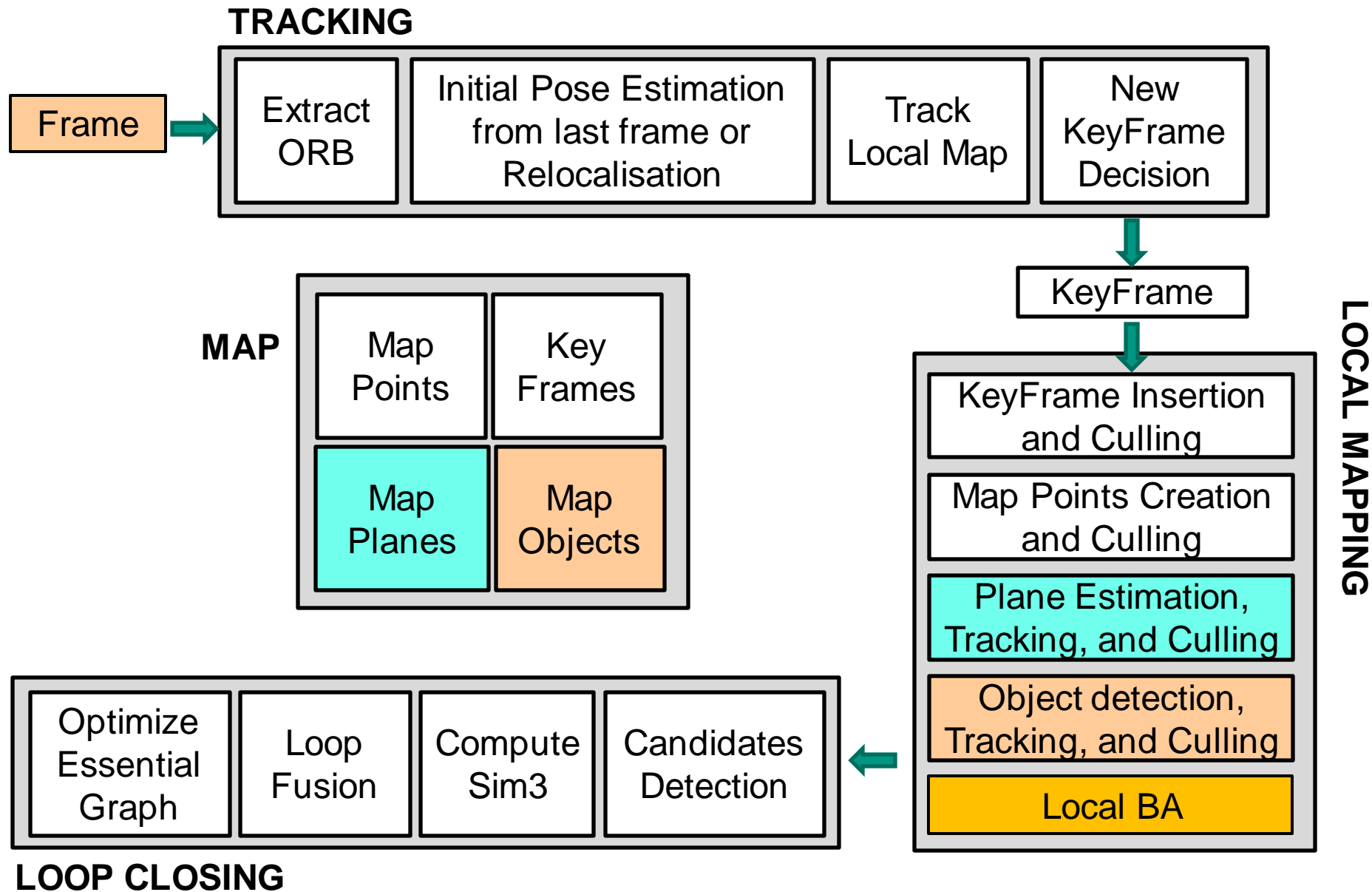


Structure SLAM with Points. Planes and Objects

Advance Robotics
Benchun Zhou
2022.09.23

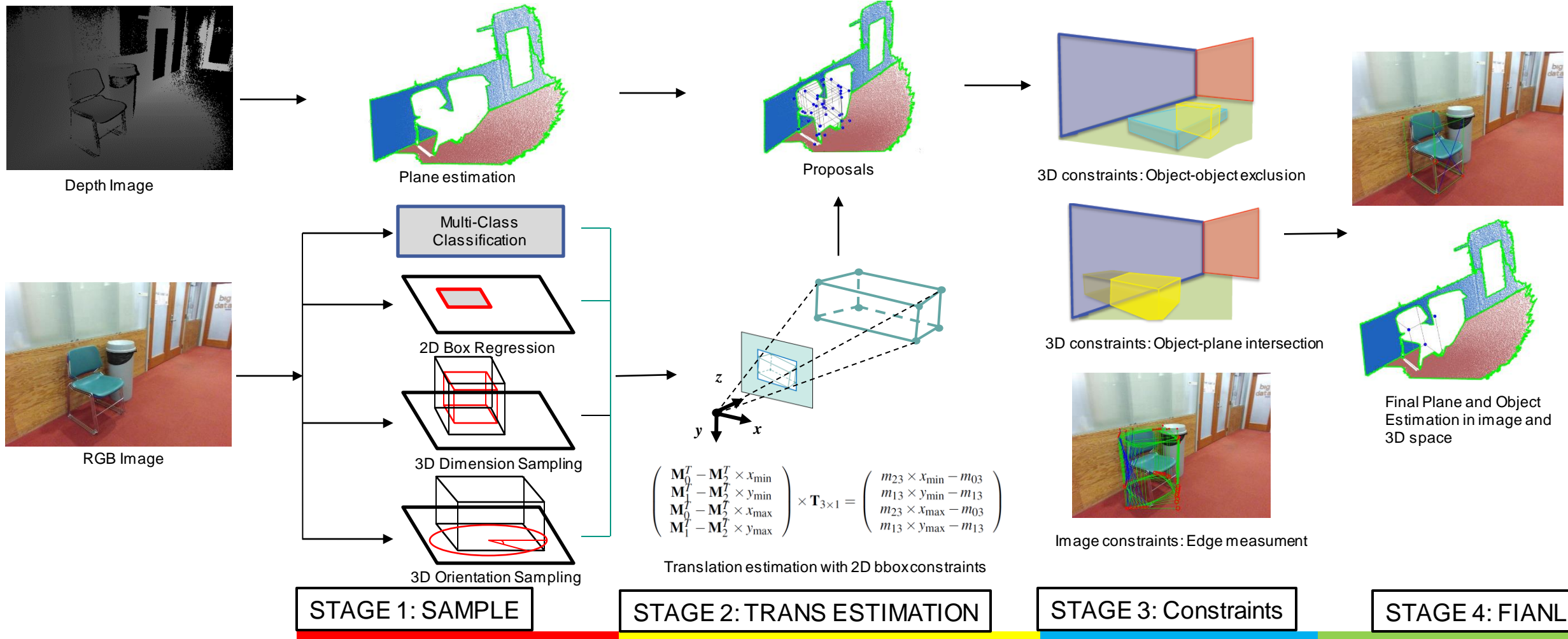
Institut für Fördertechnik und Logistiksysteme (IFL)





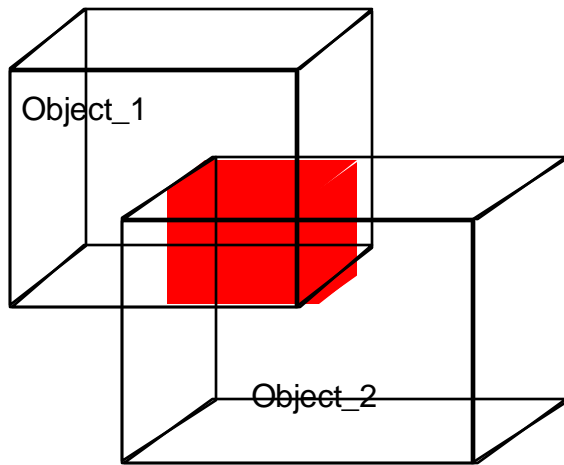
Methods: single frame understanding

■ Framework of proposed method:

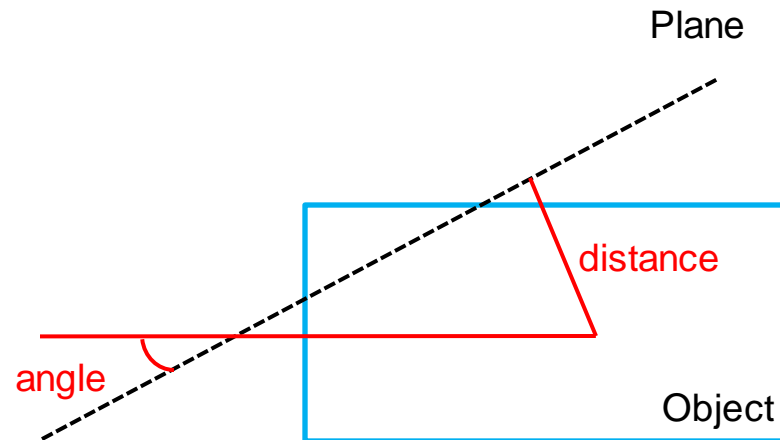


Methods: single frame understanding

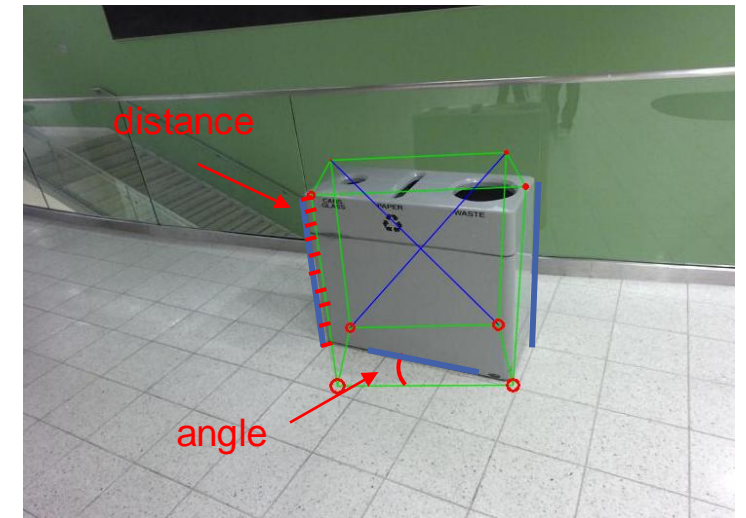
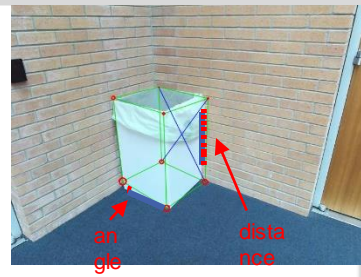
■ Object selection with constraints



a) Object-Object constraints: 3D IoU
(view from front)



b) Object-Plane constraints: angle and distance
(view from top)



c) Object-Image constraints: angle and distance
(view in image)

Result: comparison with different constraints

- Raw image with bounding box
- Final results when sample only orientation
- Final results when sample only dimension
- Final results when sample orientation and dimension

Class name	Count	Length (m)	Width (m)	Hieght (m)
bed	1286	0.7723	1.0120	0.5151
lamp	880	0.2015	0.1894	0.3959
sofa	1333	0.9186	0.4973	0.4218
sofa_chair	1770	0.4198	0.4174	0.4167
chair	19294	0.2776	0.2941	0.4202
table	4887	0.7221	0.4453	0.3569
computer	777	0.2746	0.1387	0.2290
monitor	680	0.2695	0.1120	0.2109
desk	2815	0.7007	0.3549	0.3956
recycle_bin	301	0.2088	0.1804	0.2899
garbage_bin	1016	0.2025	0.1852	0.2824
dresser	400	0.5334	0.2847	0.5876
night_stand	548	0.3166	0.2541	0.3503
box	1118	0.2014	0.1878	0.1757
shelf	796	0.7228	0.2217	0.4876
drawer	525	0.3958	0.2876	0.3868

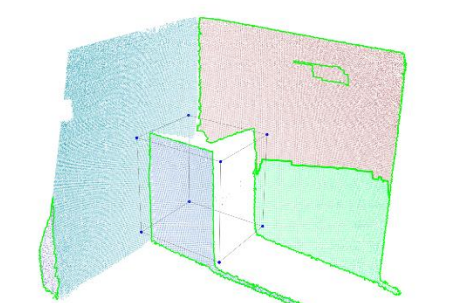
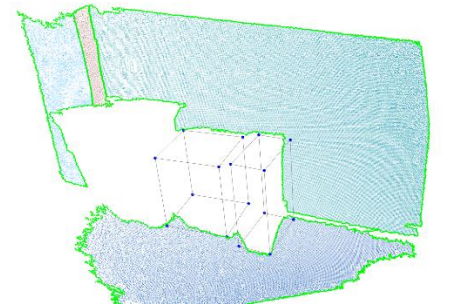
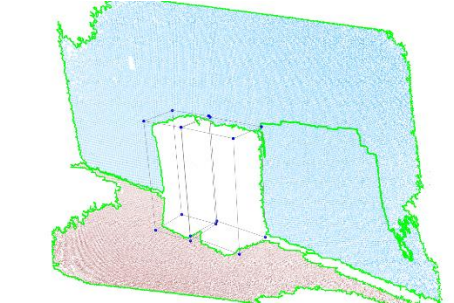
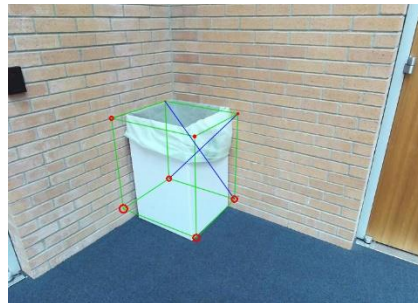
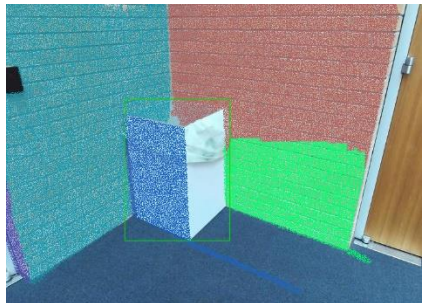
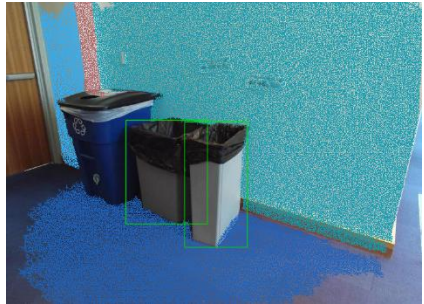
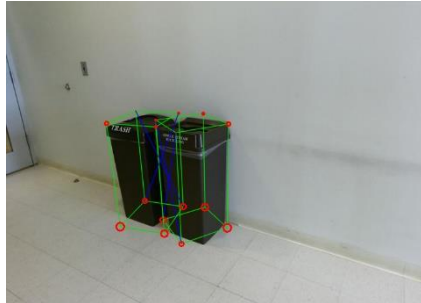
Input: planes
Input: 2D bounding box

Sample: yaw
Score: 2D constraints

Sample: yaw
Sample: dimension
Score: 2D constraints

Sample: yaw
Sample: dimension
Score: 2D constraints
Score: 3D constraints
(plot on image)

Sample: yaw
Sample: dimension
Score: 2D constraints
Score: 3D constraints
(plot on 3D space)

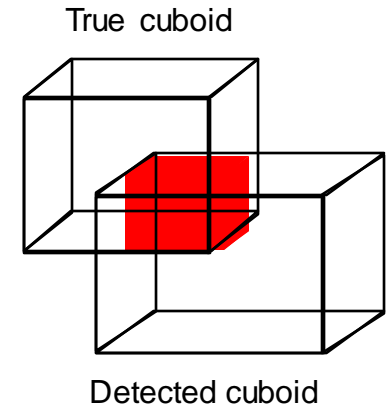


Result: comparison with different constraints

■ Comparison of different methods with 3D IoU

$$\text{3D Intersection over Union (IoU)} = \frac{V(x_i) \cap V(x_j)}{V(x_i) \cup V(x_j)}$$

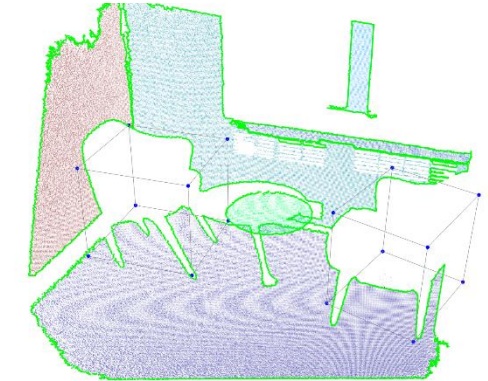
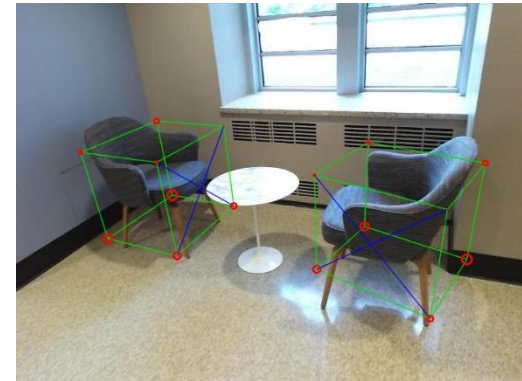
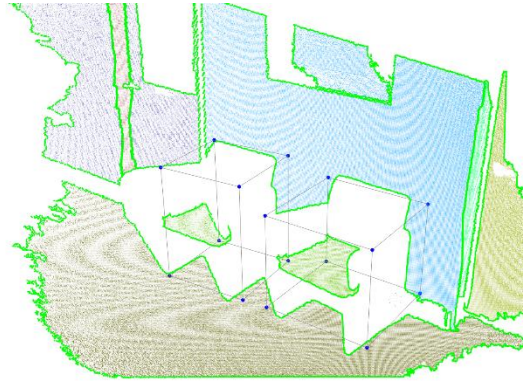
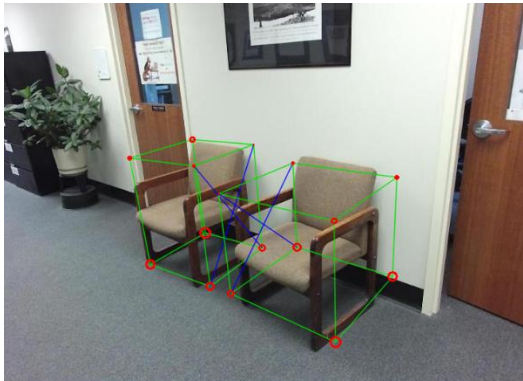
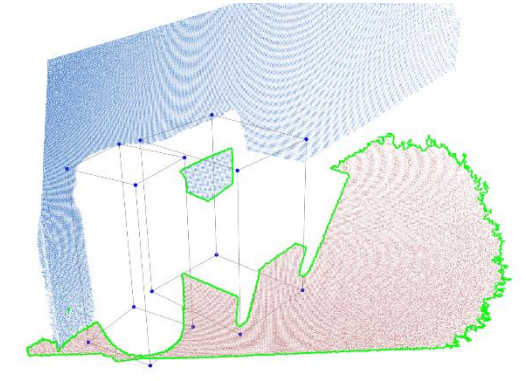
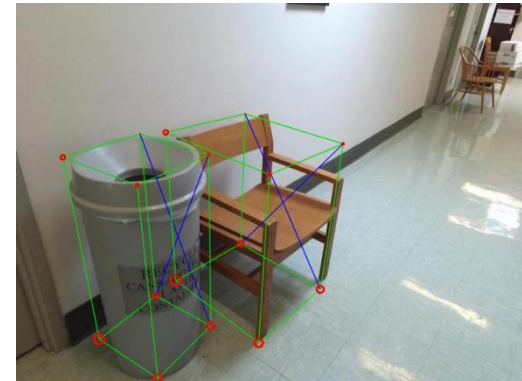
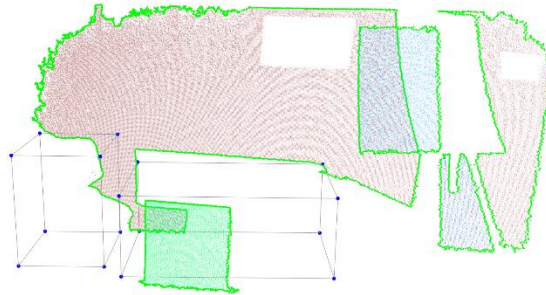
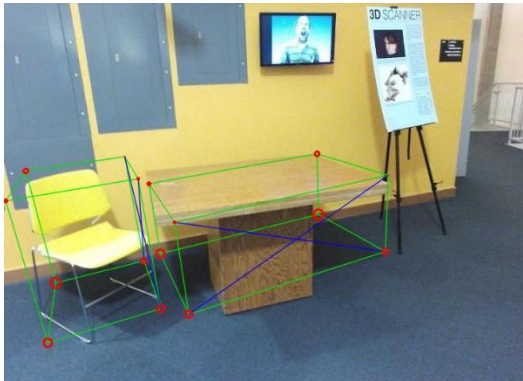
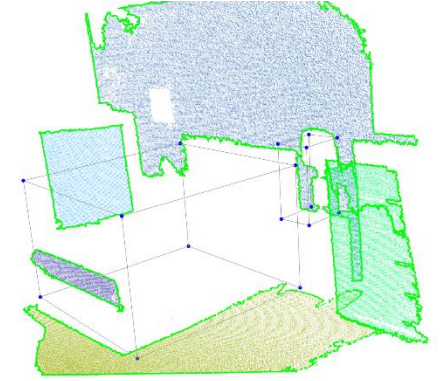
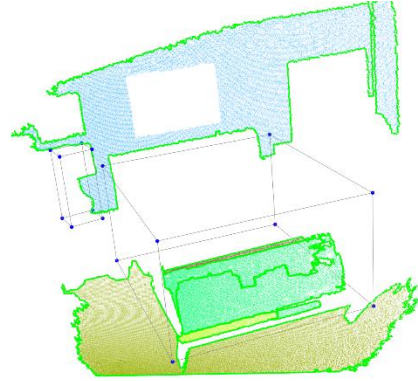
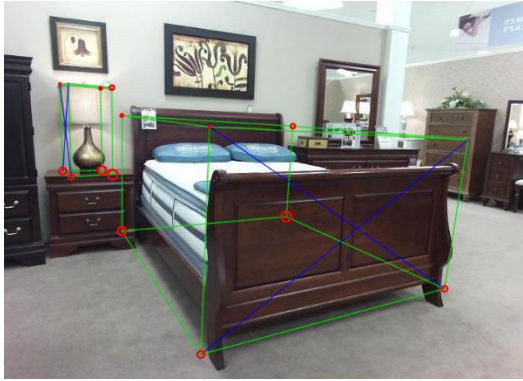
Class name	count	Sample only orientation	Sample orientation and dimension	Add plane constraints
bed	184	0.4467	0.4352	0.4979
sofa	40	0.282	0.3032	0.3189
sofa_chair	77	0.2964	0.3586	0.374
chair	163	0.3387	0.3688	0.3988
garbage_bin	77	0.358	0.2693	0.3786
night_stand	101	0.2317	0.2301	0.3559
lamp	75	0.2843	0.2575	0.2578
table	25	0.3177	0.2481	0.2576



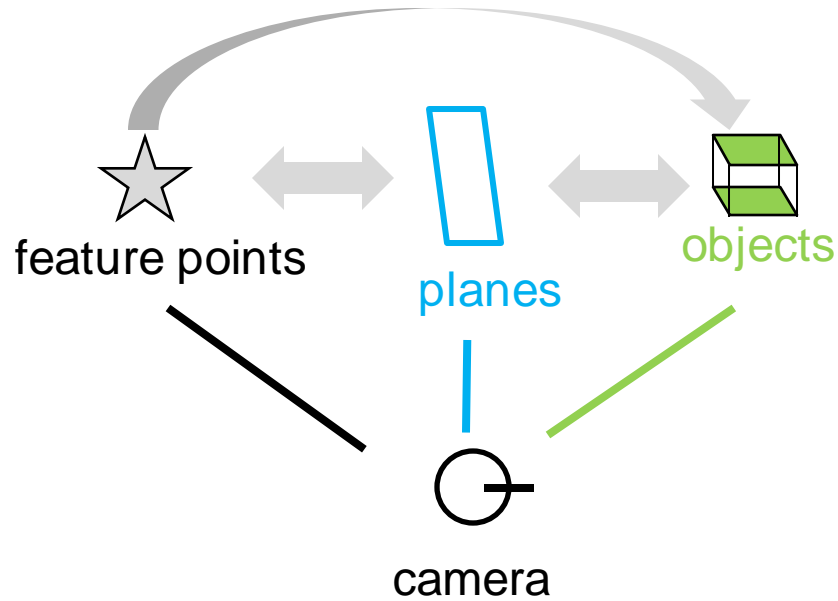
Result: other objects

- Different metrics of our methods: 3D IoU (\uparrow) . other error (\downarrow)

Class name (label_v6)	count	3D IoU (Intersection over Union)	Translation error (m)	Yaw error (rad)	Dimension error (m)
bed	184	0.4979	0.3963	0.1602=9.1°	[0.1527 0.1253 0.1126]
sofa	40	0.3189	0.4352	0.1569=9.0°	[0.1550 0.0968 0.0657]
sofa_chair	77	0.374	0.3244	0.1601=9.1°	[0.0469 0.0654 0.0575]
chair	163	0.3988	0.228	0.1637=9.4°	[0.0512 0.0477 0.0488]
garbage_bin	77	0.3786	0.1633	0.1090=6.2°	[0.0440 0.0391 0.0429]
night_stand	101	0.3559	0.2420	0.1634	[0.0505 0.0419 0.0537]
lamp	75	0.2578	0.2376	0.1371	[0.0368 0.0413 0.0462]
table	25	0.2576	0.5165	0.1804	[0.1227 0.0940 0.0787]

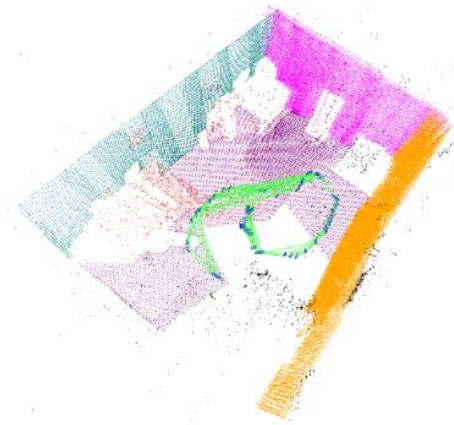


Methods: data association

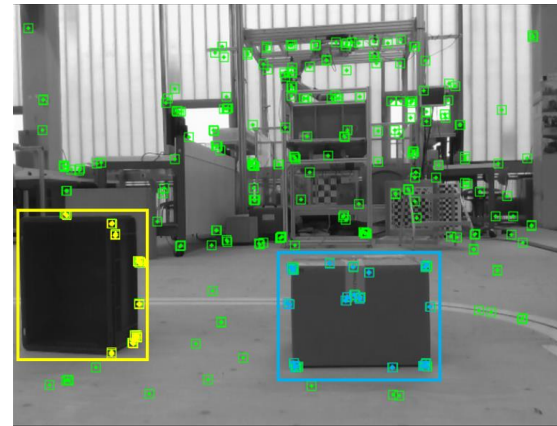


Data association in single frame

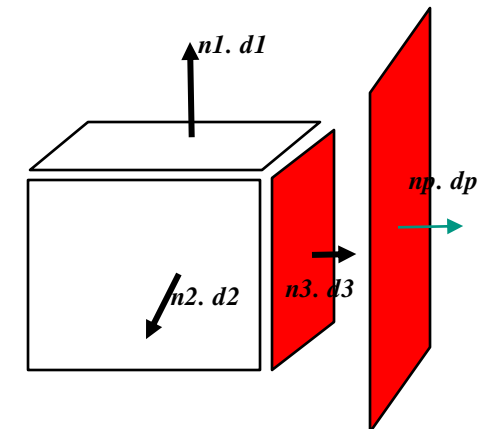
- Points – planes (orthogonal distance $< 0.1\text{m}$)
- Points – object (points inside object 2D bounding box)
- Plane – object (angle and distance)



Point-plane association

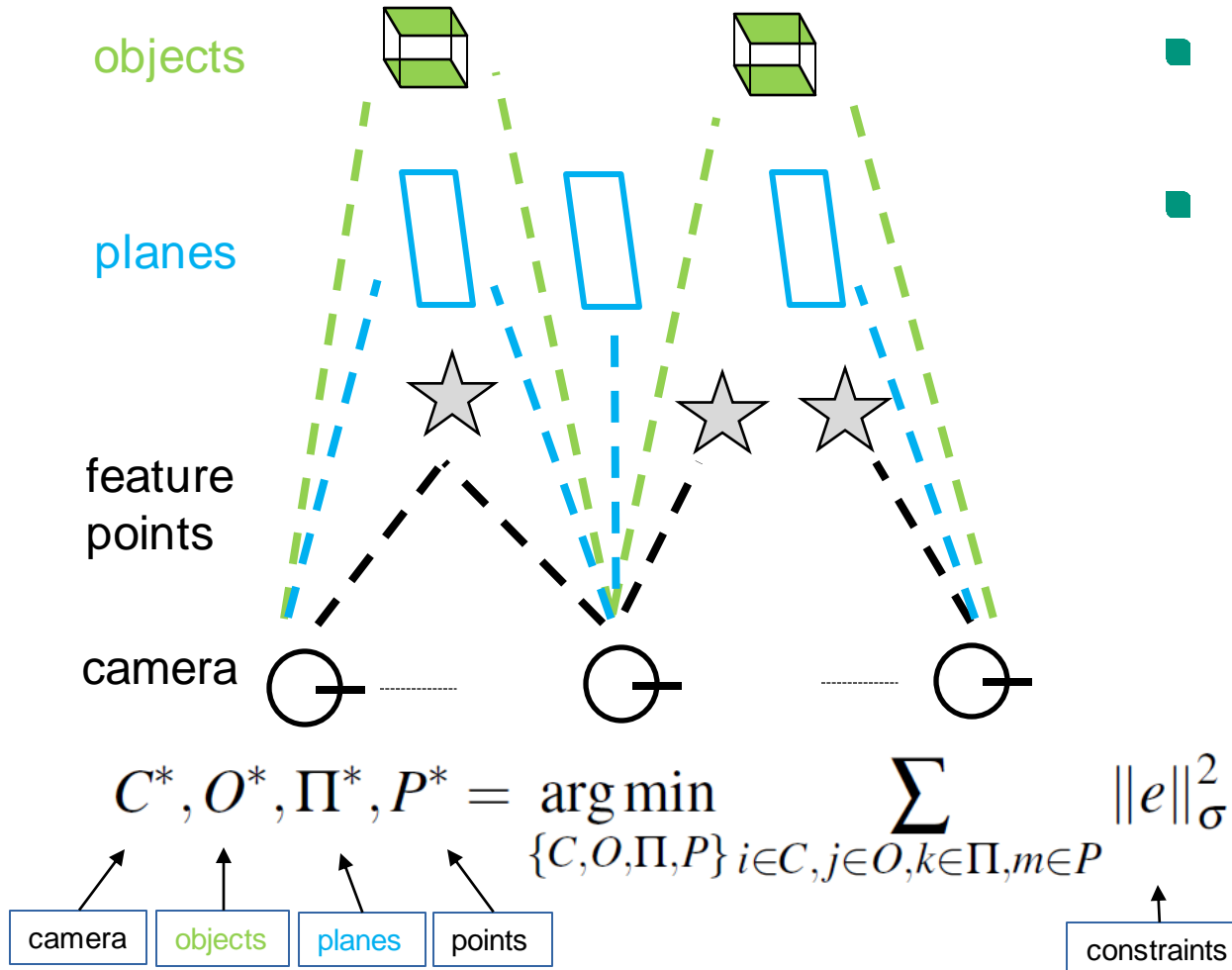


Point-object association



Object-plane association

Methods: SLAM with points. planes. and objects



- Landmark
 - Camera. Points. Planes. objects
- Constraints
 - Cam – points
 - Cam – planes
 - Cam – objects
 - Points – planes
 - Points – objects
 - Planes - objects

$$e(P_w, \mathbf{T}_{cw}) = u_c - \rho(\mathbf{T}_{cw}^{-1}, P_w)$$

$$e(\pi_w, \mathbf{T}_{cw}) = \left\| q(\pi_m) - q\left(\mathbf{T}_{cw}^{-\top} \pi_w\right) \right\|$$

$$e(O_w, \mathbf{T}_{cw}) = \sum_{m \in \{1,8\}} z_m - \rho(\mathbf{T}_{cw}^{-1}, O_w)$$

$$e(P, \Pi) = \|\pi P\|$$

$$e(P, O) = \max(|T_o^{-1}P| - \mathbf{d}_m, \mathbf{0})$$

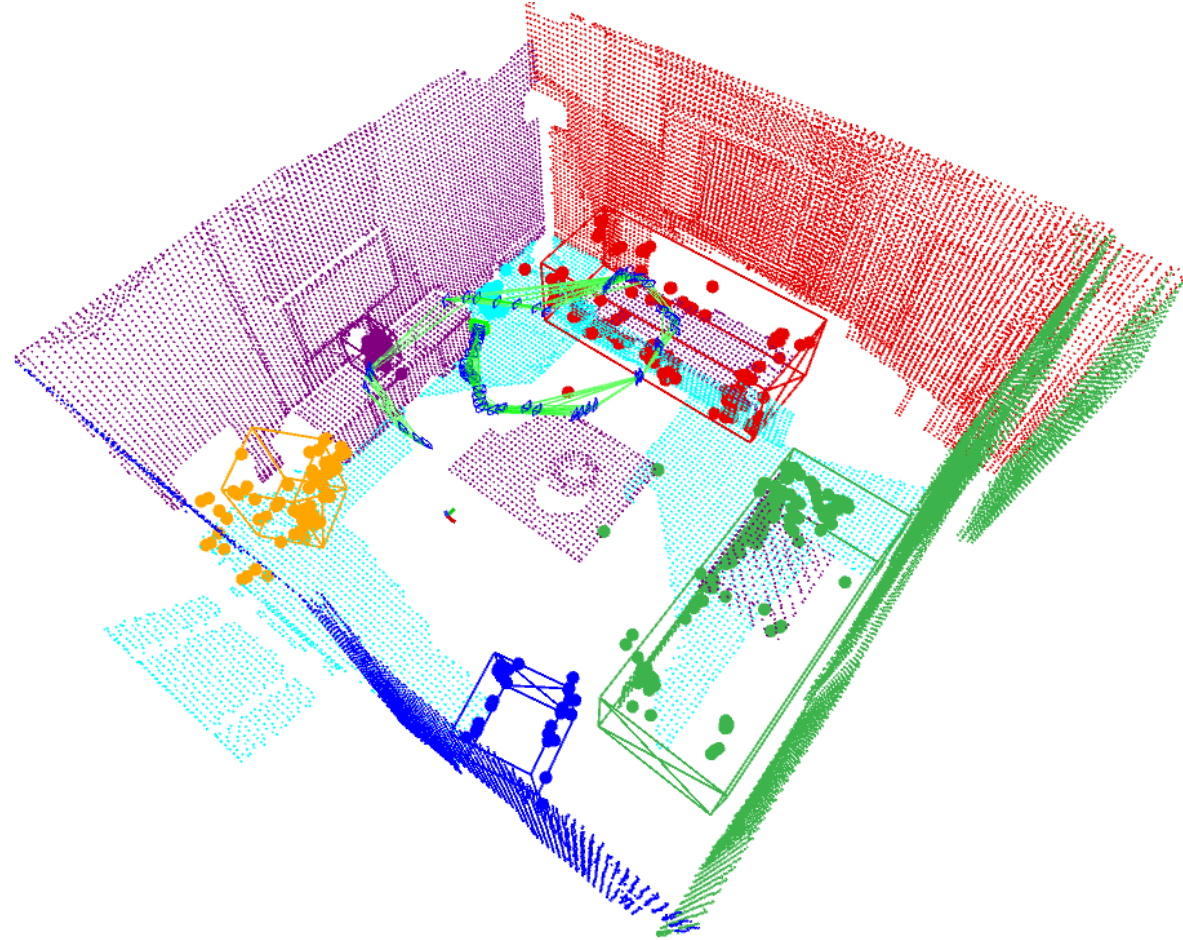
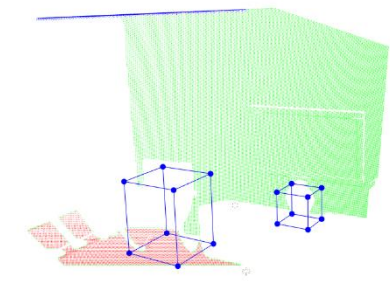
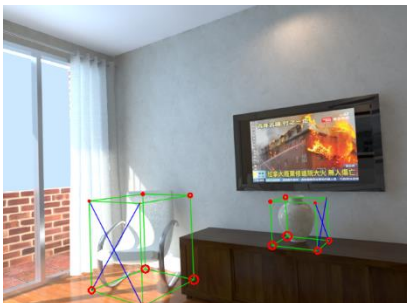
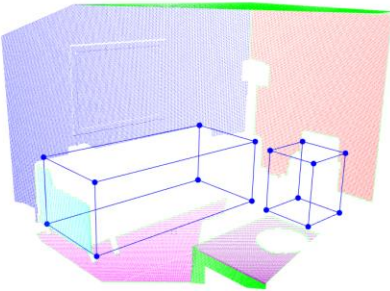
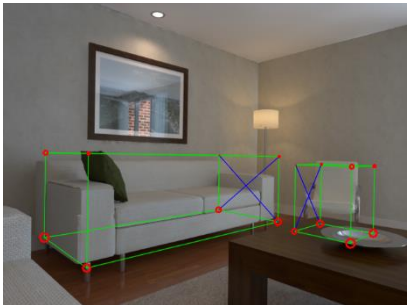
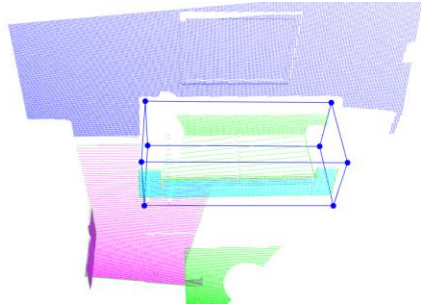
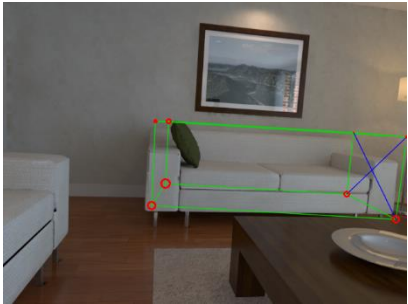
$$e(\Pi, O) = \|\min(q(\pi) - q(\pi_{oi}))\|$$

Result on datasets

- Dataset:
 - ICL NUIM (Office and Living room)
- Comparison
 - Points only SLAM (ORB SLAM 2)
 - Points + Plane SLAM
 - Points + Object SLAM
 - Points + Plane + Object SLAM (Ours)

Result on datasets

■ ICL NUIM Living Room Dataset



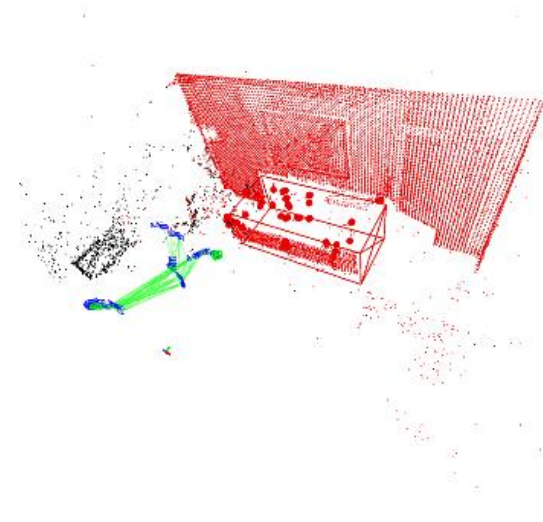
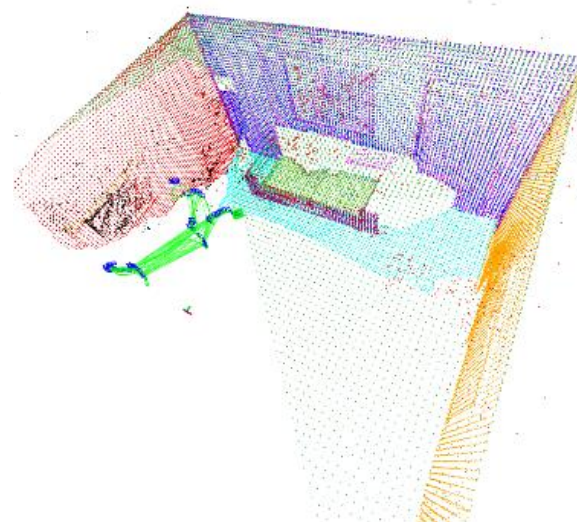
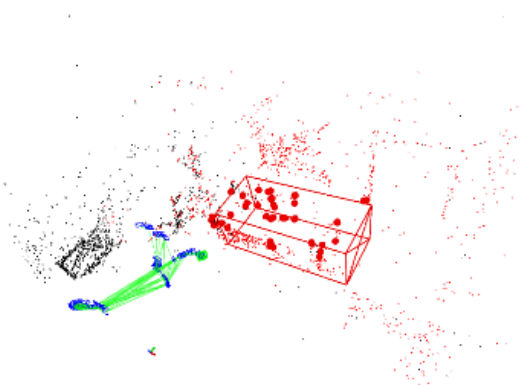
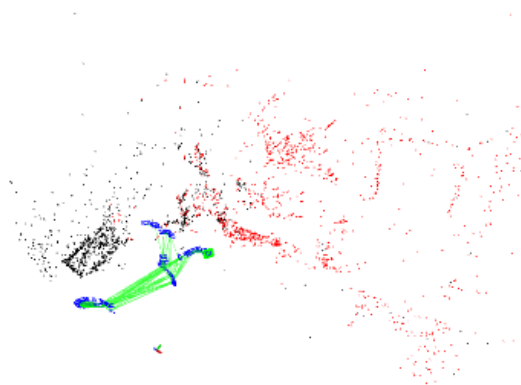
Point Map

Point Object Map

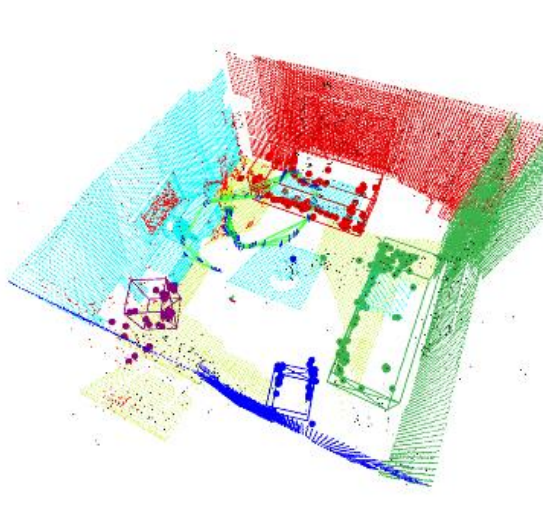
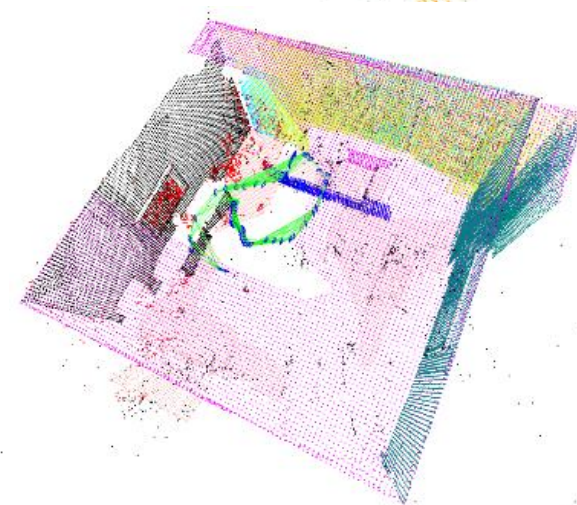
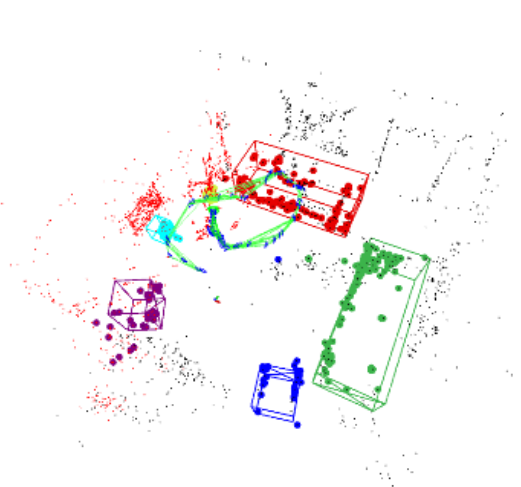
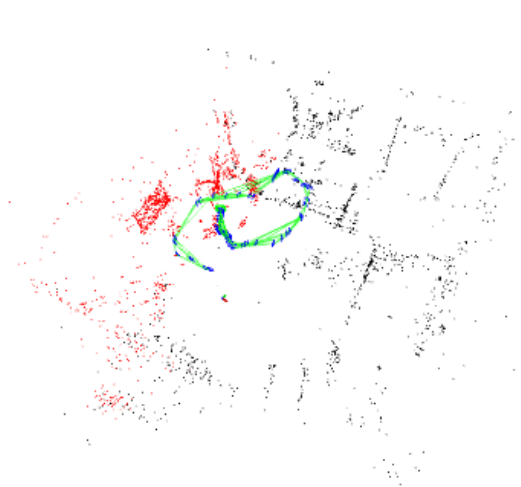
Point Plane Map

Point Plane Object Map

Living
room
kt-0

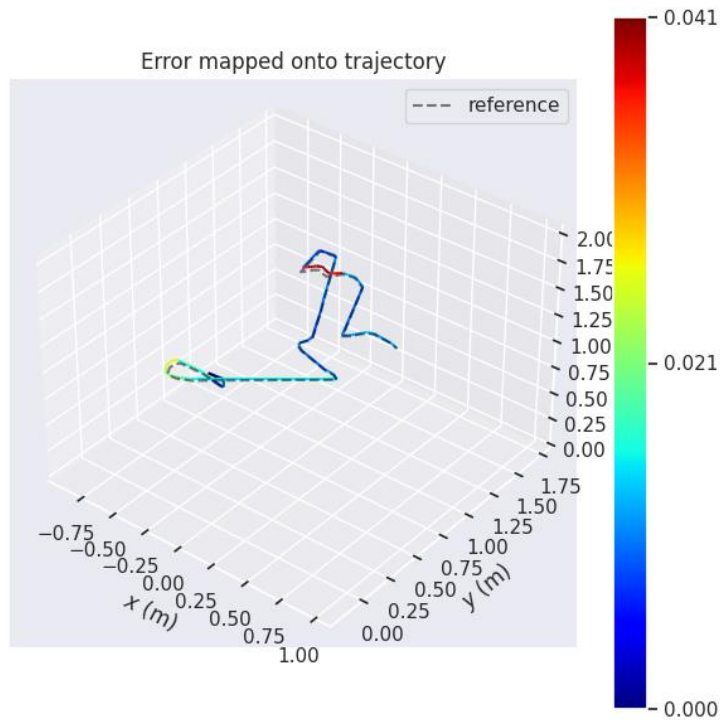


Living
room
kt-2

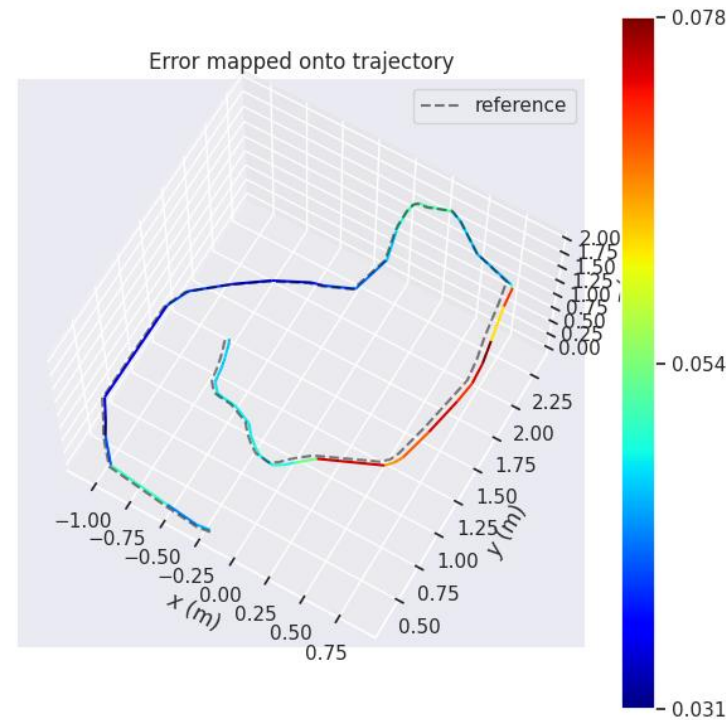


SLAM Trajectory

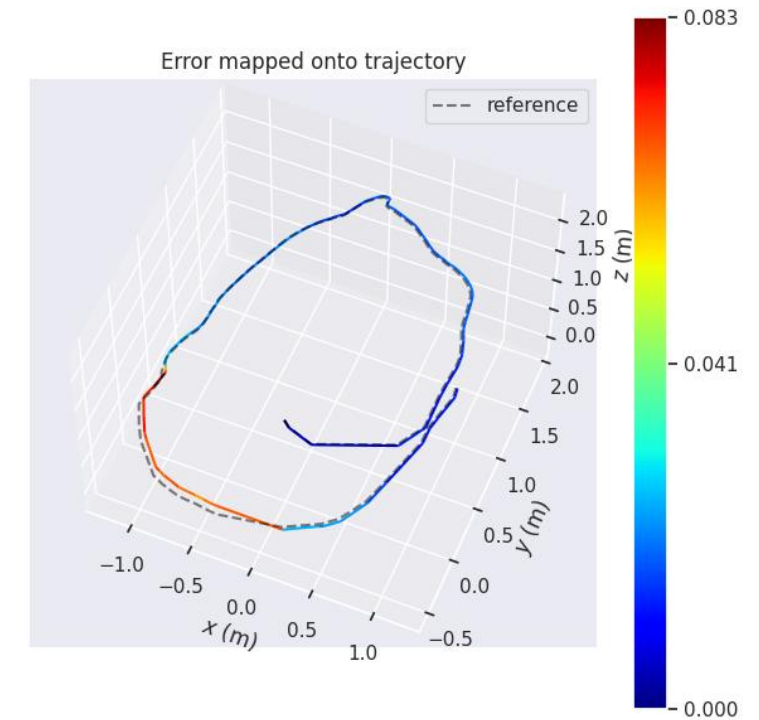
Method	Living room 0	Living room 2	Living room 3
Point only SLAM	0.153577	0.076254	0.557247
Point-plane SLAM	0.079896	0.089365	0.044567
Point-object SLAM	0.104748	0.089919	0.656504
Point-plane-object SLAM	0.078700	0.065538	0.041919



a) Living room kt-0



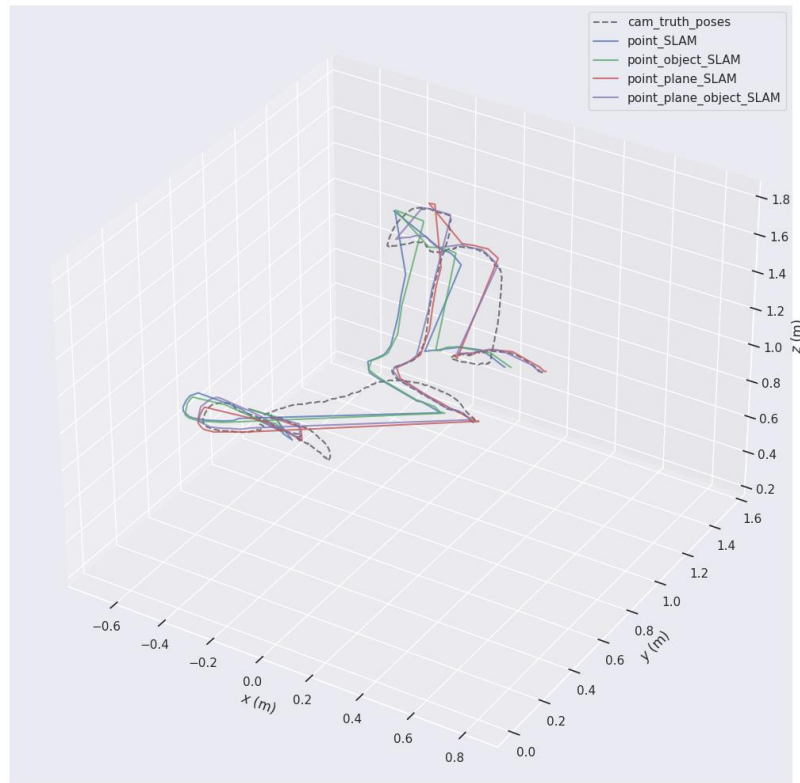
b) Living room kt-2



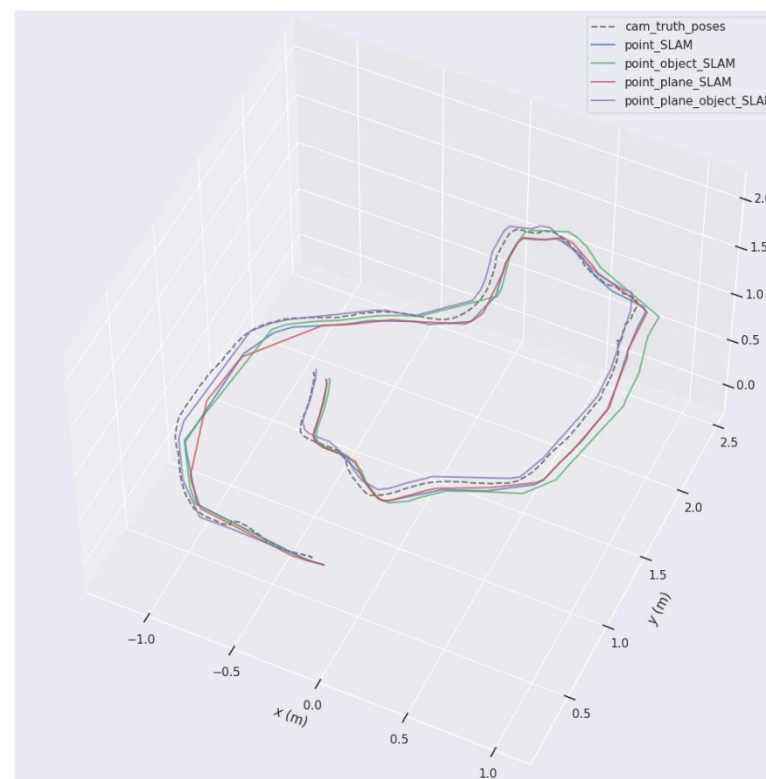
c) Living room kt-3

SLAM Trajectory

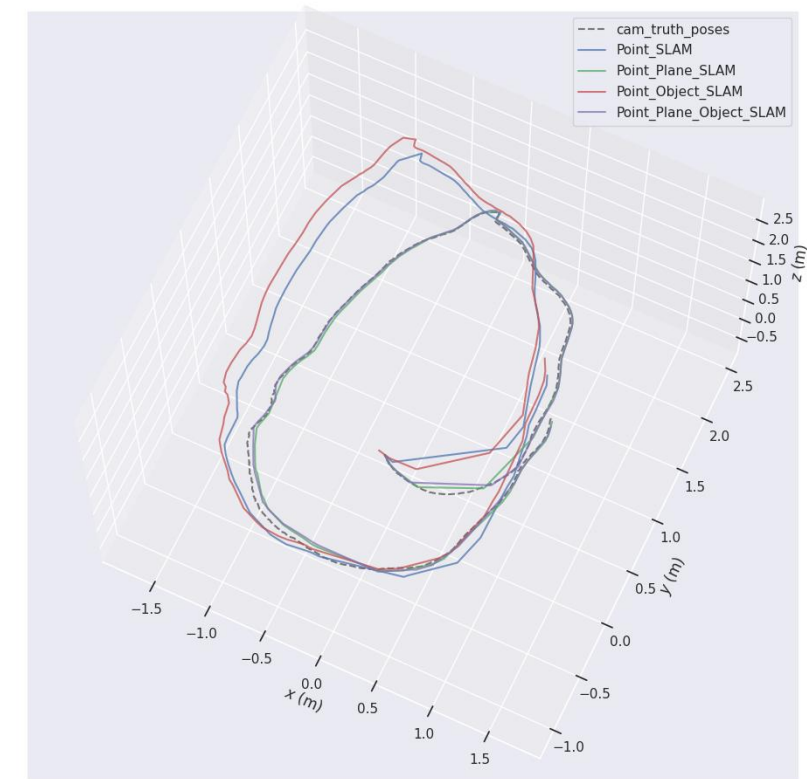
Method	Living room 0	Living room 2	Living room 3
Point only SLAM	0.153577	0.076254	0.557247
Point-plane SLAM	0.079896	0.089365	0.044567
Point-object SLAM	0.104748	0.089919	0.656504
Point-plane-object SLAM	0.078700	0.065538	0.041919



a) Living room kt-0



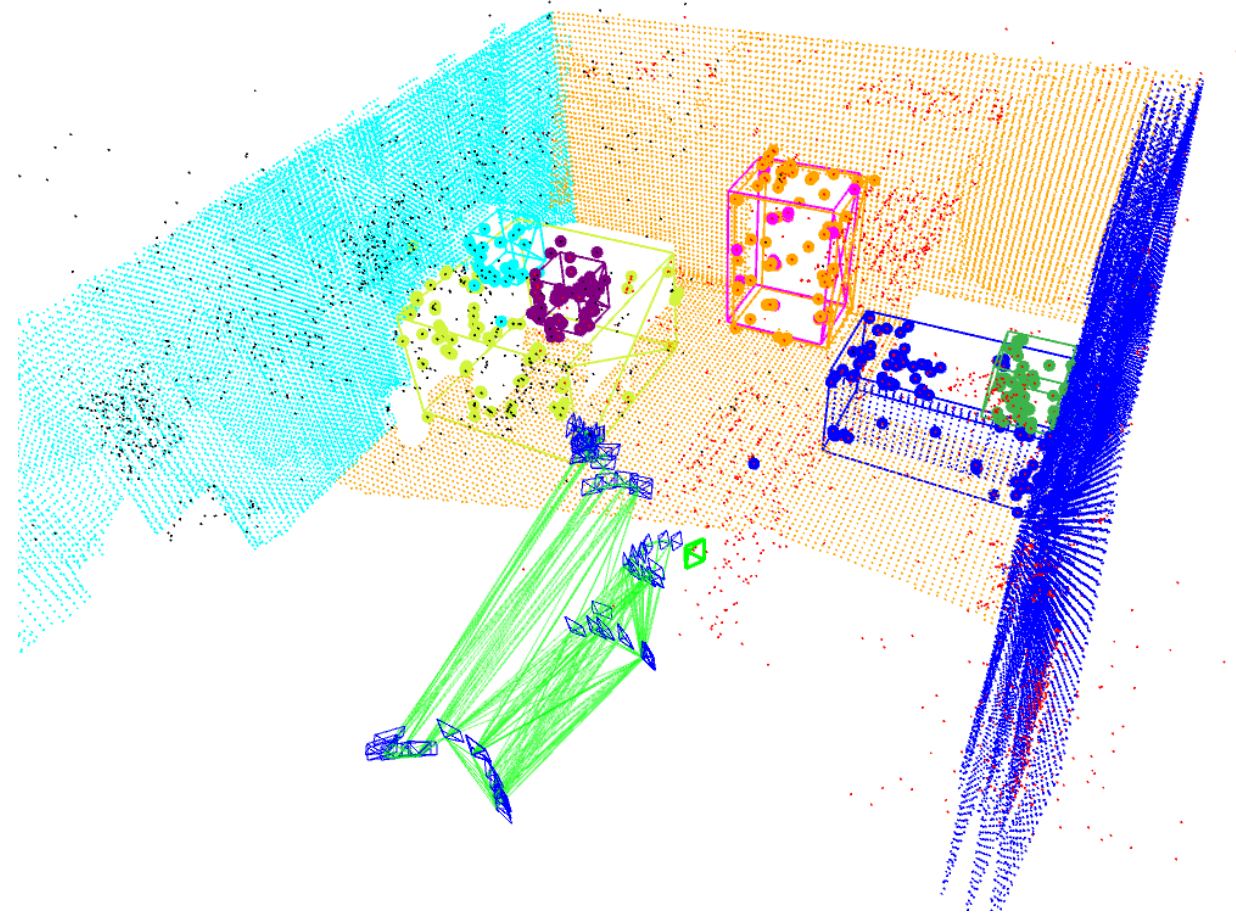
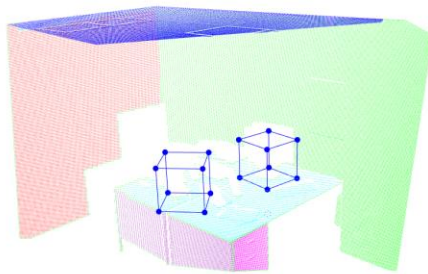
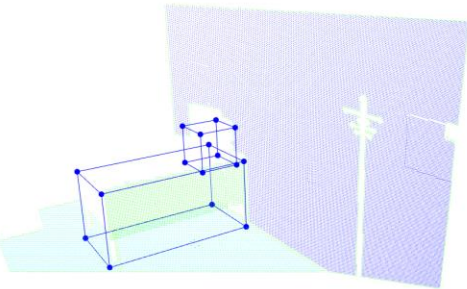
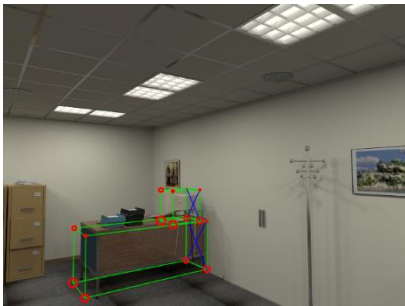
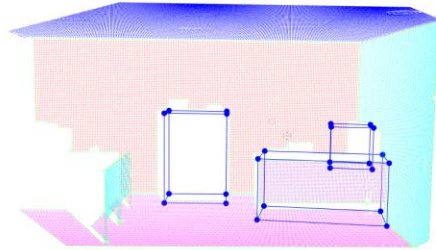
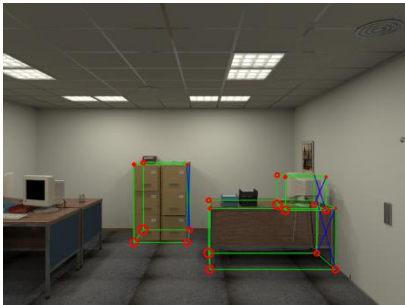
b) Living room kt-2



c) Living room kt-3

Result on datasets

■ ICL NUIM Office Dataset



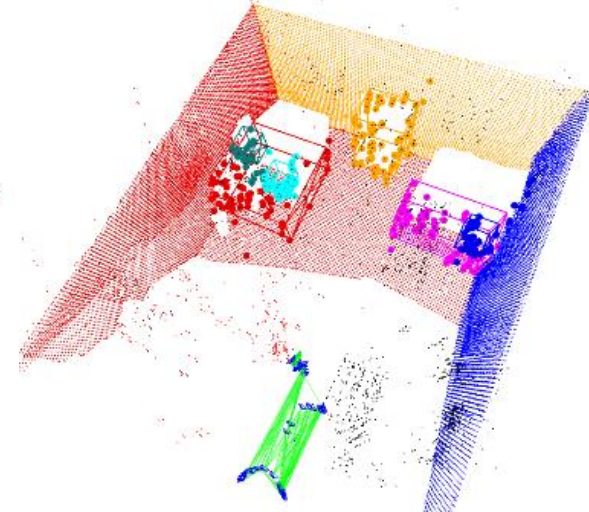
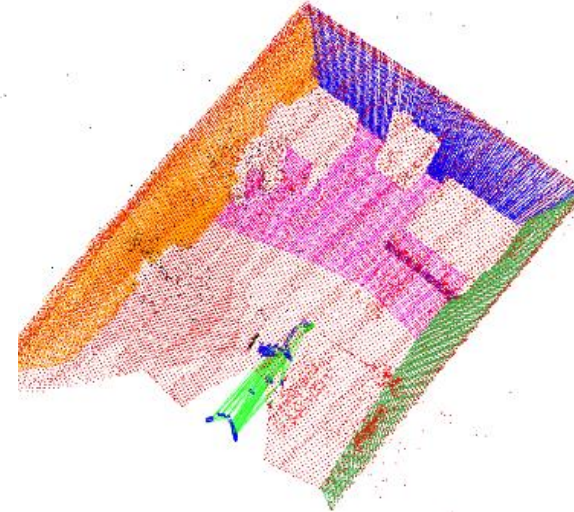
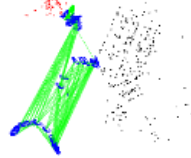
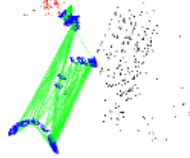
Point Map

Point Object Map

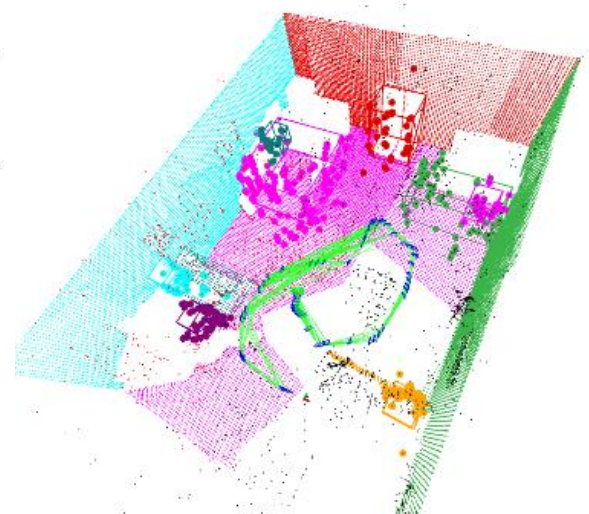
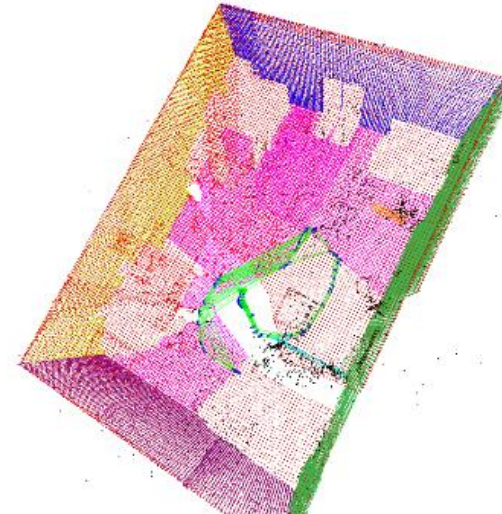
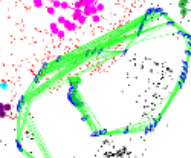
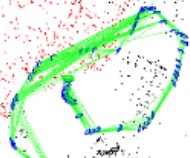
Point Plane Map

Point Plane Object Map

Office
kt-0

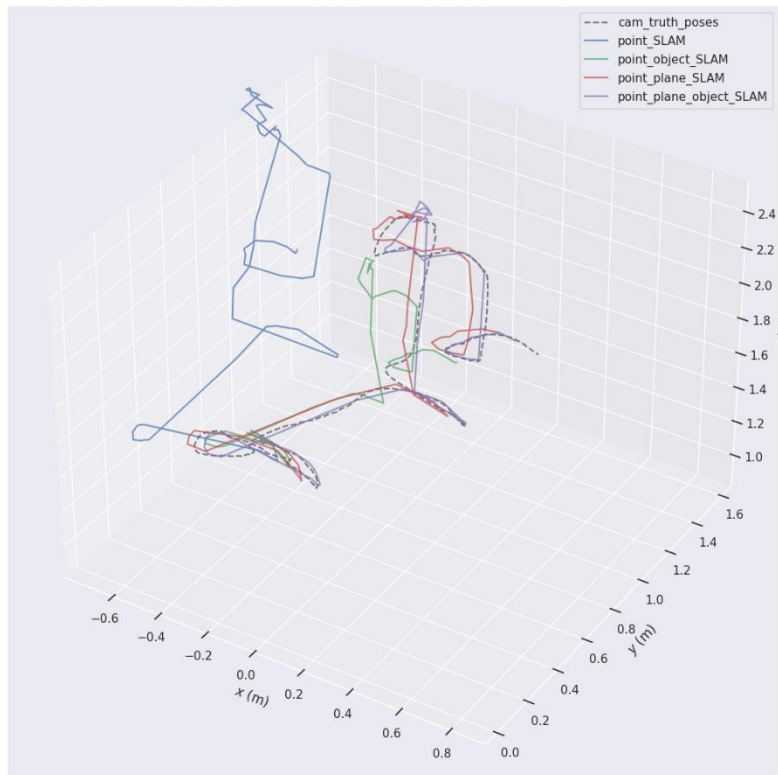


Office
kt-2

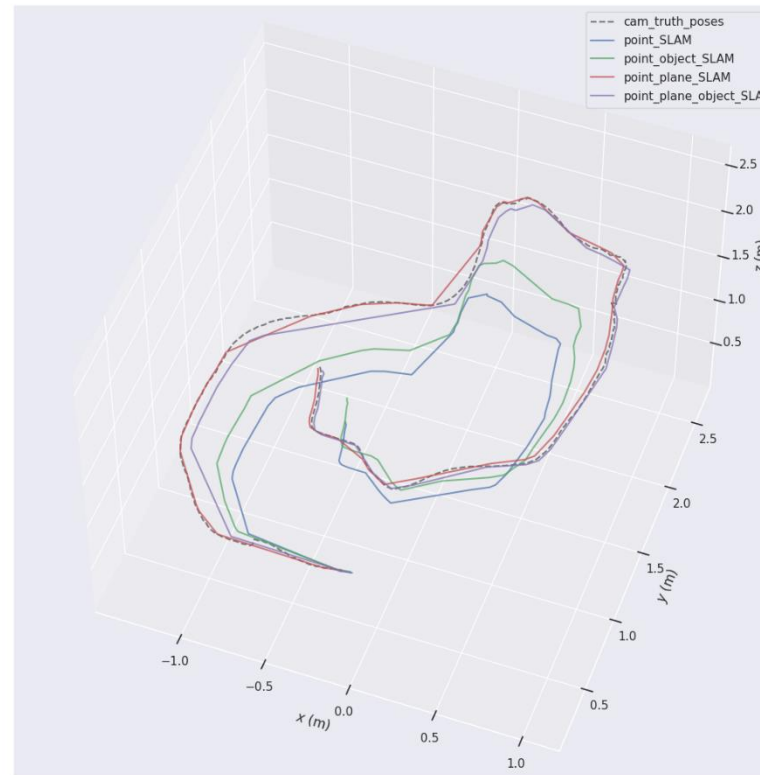


SLAM Trajectory

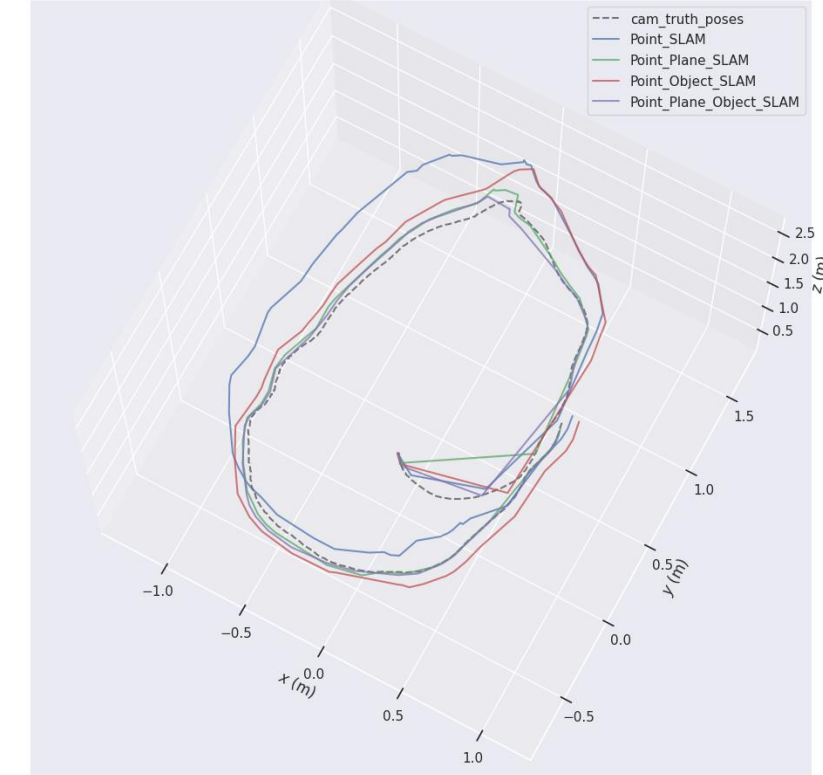
Method	Office 0	Office 2	Office 3
Point only SLAM	0.639634	0.395605	0.188552
Point-plane SLAM	0.092112	0.045794	0.070988
Point-object SLAM	0.266788	0.296422	0.083829
Point-plane-object SLAM	0.087932	0.059703	0.061738



a) Office kt-0



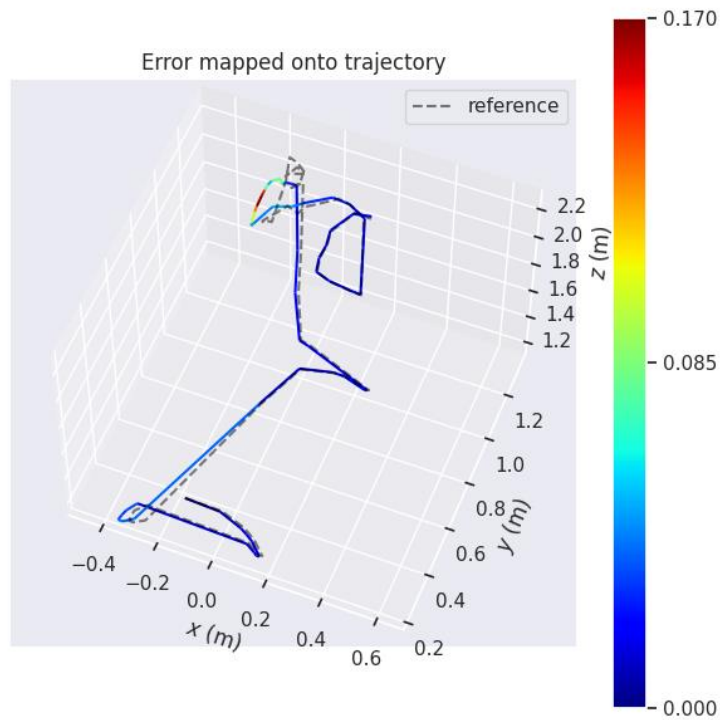
b) Office kt-2



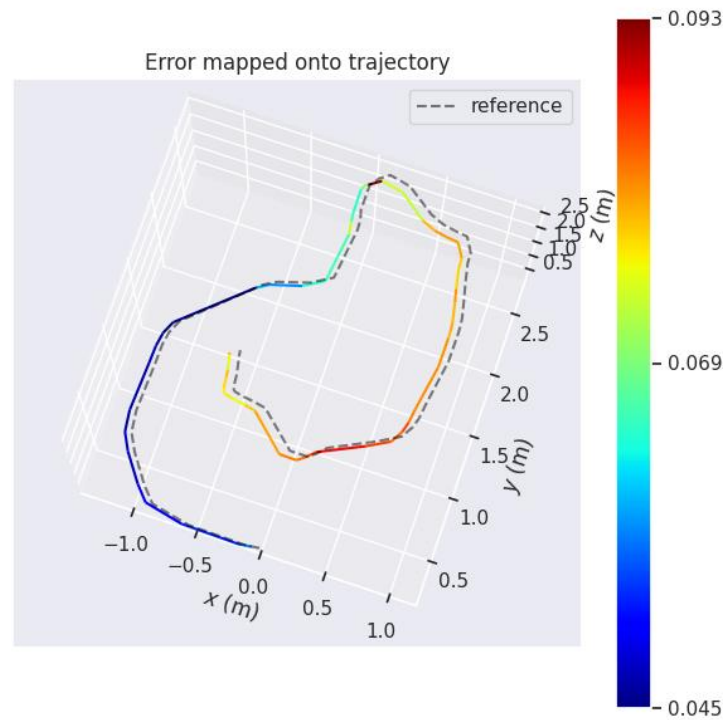
c) Office kt-3

SLAM Trajectory

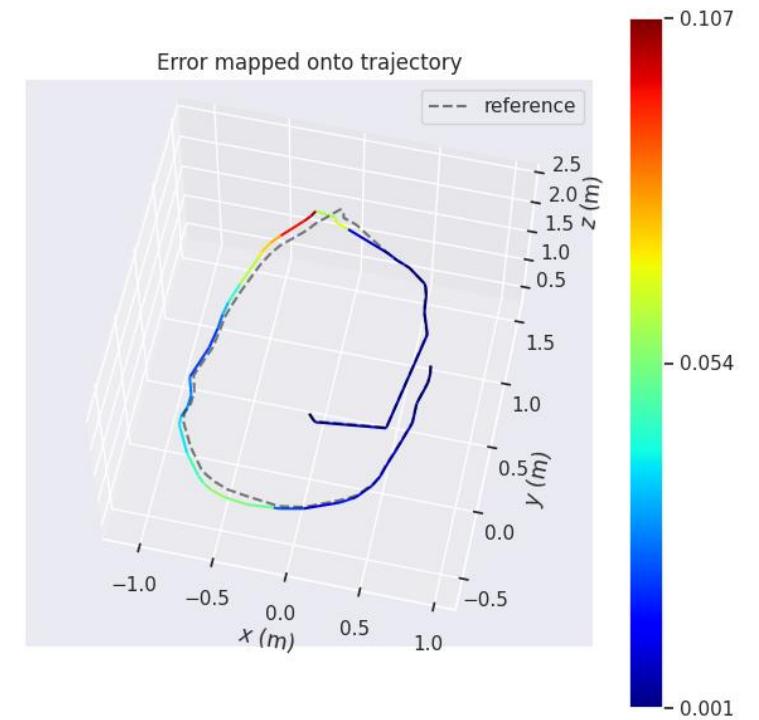
Method	Office 0	Office 2	Office 3
Point only SLAM	0.639634	0.395605	0.188552
Point-plane SLAM	0.092112	0.045794	0.070988
Point-object SLAM	0.266788	0.296422	0.083829
Point-plane-object SLAM	0.087932	0.059703	0.061738



a) Office kt-0



b) Office kt-2



c) Office kt-3

Structure SLAM with Points, Planes and Objects

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Result on datasets

■ Run time analysis

dataset	Tasks	Average time (mSec)
Single image preprocess	Plane estimation	109.99
	Object detection	97.386
	Edge detection	18.831
Indoor ICL room dataset	Tracking thread	47.886
	Point only BA	63.240
	Point plane BA	135.55
	Point plane object BA	157.48



Thanks for your listening

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