Uni-SLAM

Uncertainty-Aware Neural Implicit SLAM for Real-Time Dense Indoor Scene Reconstruction

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WACV 2025
TUCSON, ARIZONA • FEB 28 - MAR 4

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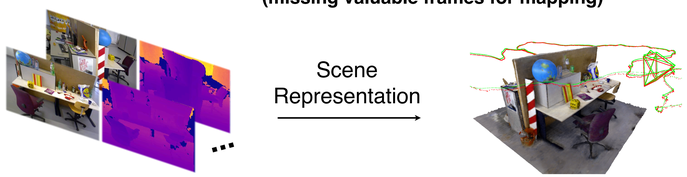
Introduction

Neural implicit SLAM common problems:

- Noisy input: blurry RGB, invalid depth
- Insufficient scene representation (forgetting)
- Slow convergence
- Lack of strategy for keyframe selection (missing valuable frames for mapping)

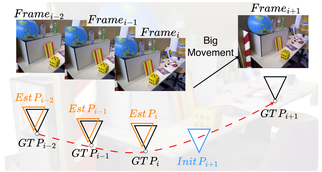


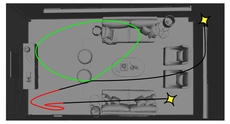
Motivation

- **Model-free predictive uncertainty, which evaluates the rendered quality along a ray.**

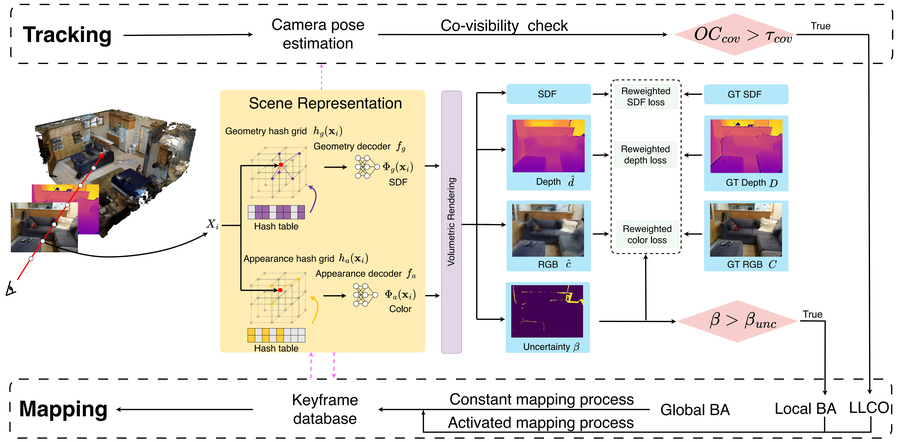
$$p(r) = \sum_{i=1}^{N} w_i = 1 - \exp\left(-\sum_{i=1}^{N} \sigma(\mathbf{x}_i)\right) \qquad \beta_m = (1 - p(r_m))^2$$

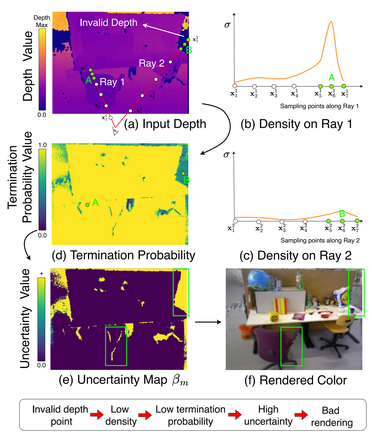
- **Scene representation: Compared to multi-resolution grids in Nice-SLAM[CVPR'2022], hybrid representation in Co-SLAM[CVPR'2023] and BSLAM[CVPR'2024], feature-planes in ESLAM[CVPR'2023] and points in Loopy-SLAM[CVPR'2024], our hash grid achieves a balance between rendering speed and rich spatial representation.**
- **Active Strategic BA: at different stages, keyframes are selected to capture the most valuable information.**





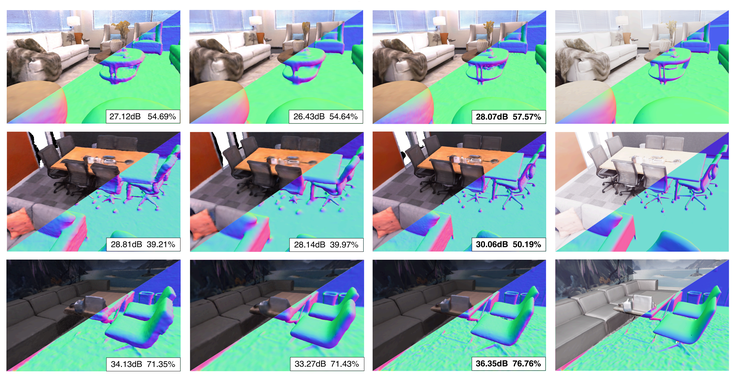
Pipeline



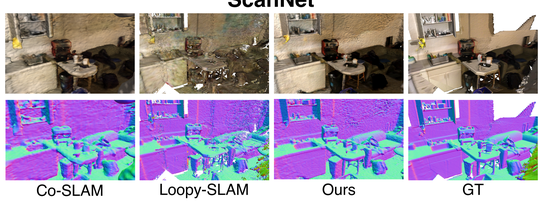


Results

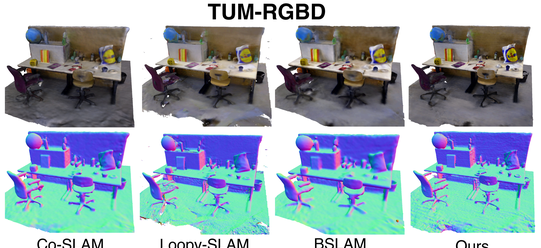
Replica



ScanNet



TUM-RGBD

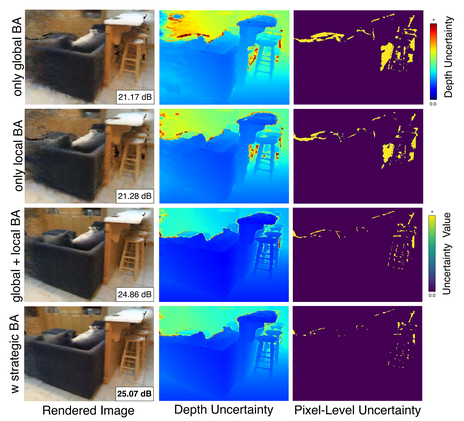


Analysis

a) Reconstruction & Rendering

Dataset	Method	Depth L1 ↓	Acc. [cm] ↓	Comp. Ratio[%] ↑	PSNR [dB] ↑	SSIM ↑	LPIPS ↓
Replica	Nice-SLAM	3.18	1.90	36.93	24.42	0.8091	0.2335
	Co-SLAM	2.15	1.16	55.94	30.27	0.9396	0.2468
	ESLAM	1.18	0.97	63.99	30.19	0.9421	0.2433
	BSLAM	2.52	1.12	57.18	29.55	0.9335	0.2361
	Ours	**0.89**	**0.92**	**66.86**	**31.62**	**0.9584**	**0.1853**

b) Tracking & Runtime

Dataset	Method	ATE RMSE [cm] ↓	Tracking [ms/it.] ↓	Mapping [ms/it.] ↓	FPS ↑	Param. ↓
TUM-RGBD	Nice-SLAM	4.41	33	103	0.09	120.95
	Co-SLAM	2.59	**4.3**	15.6	**6.4**	**1.68**
	ESLAM	2.14	20.5	22.3	0.33	9.51
	BSLAM	2.39	251	370	0.95	19.76
	Ours	**2.05**	12.3	**13.7**	2.7	3.58
ScanNet	Nice-SLAM	10.7	11.3	41.2	1.34	22.04
	Co-SLAM	9.4	**5.6**	12.7	**5.7**	**1.74**
	ESLAM	7.4	20.5	22.3	1.57	17.63
	BSLAM	9.56	250	400	0.52	18.5
	Ours	**7.01**	6.3	**11.7**	4.88	3.39

C) Ablation Study on Bundle Adjustment