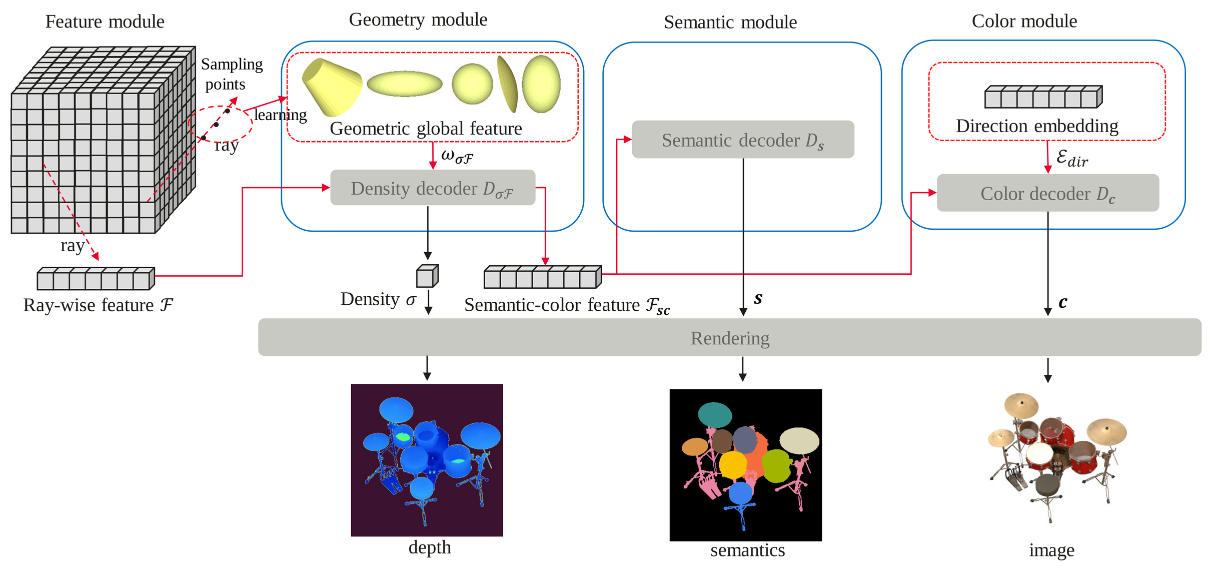
IS-NEAR: Implicit Semantic Neural Engine and Multi-Sensor Data Rendering With 3D Global Feature

{ [1]Tiecheng Sun, [2,3]Wei Zhang, [1]Xingliang Dong, [1]Tao Lin }
[1]Huawei 2012 Laboratories
[2]University Of Stuttgart,
[3]Huawei Munich Research Center

Implicit Data Engine



The contributions of this paper:

- IS-NEAR is the first to associate all independent NeRF rays with 3D global features, which improves the geometry, color, semantics and labeling efficiency.
- We customize the back-propagation to eliminate the differences between geometric and semantic inferences.
- The carefully loss and network design makes a trade-off among efficiency, semantics, color and geometry, superior to the SOTA methods.
- The engine can be applied to indoor, outdoor and objects semantic labeling, texture rerendering, and robot simulation.

3D Global Features

The point-to-surface representation is expressed as:

$$d = \boldsymbol{\pi}^T \cdot \boldsymbol{X}, \tag{1}$$

where $\boldsymbol{\pi}$ is the coefficients vector of the quadratic terms $\boldsymbol{X}$, namely the global feature, $\boldsymbol{X}$ is expressed as:

$$\boldsymbol{X} = (x^2, y^2, z^2, xy, xz, yz, x, y, z), \tag{2}$$

x, y, z is the sampling points on each ray.

$$\boldsymbol{\omega} = L_{emb}(1 - (sigmoid(\pi^T \cdot \boldsymbol{X}))). \tag{3}$$

$\boldsymbol{\omega}$ is related to the distance between the point and the global surface.

Implicit Fields

The point density σ, semantics $\boldsymbol{s}$ and color $\boldsymbol{c}$ are defined as:

$$[\sigma, \mathcal{F}_{\boldsymbol{sc}}] = \boldsymbol{\omega}_{\sigma\mathcal{F}} \cdot D_{\sigma\mathcal{F}}(\mathcal{F}), \tag{4}$$

$$\boldsymbol{s} = D_{\boldsymbol{s}}(\mathcal{F}_{\boldsymbol{sc}}), \tag{5}$$

$$\boldsymbol{c} = D_{\boldsymbol{c}}([\mathcal{F}_{\boldsymbol{sc}}, \mathcal{E}_{dir}]), \tag{6}$$

Losses

$$\mathcal{L}_c = \frac{1}{B}\sum_{b=1}^{B} \|\boldsymbol{c}_b - \hat{\boldsymbol{c}_b}\|^2, \tag{7}$$

$$\mathcal{L}_s = -\sum_{r\in\mathcal{R}}\sum_{k=1}^{N_c} w_k \hat{p}_k(r) \log p_k(r), \tag{8}$$

$$w_k = \lfloor_l \frac{n_k}{\sum_{i=0}^{N_c} n_i} \rceil^h, \tag{9}$$

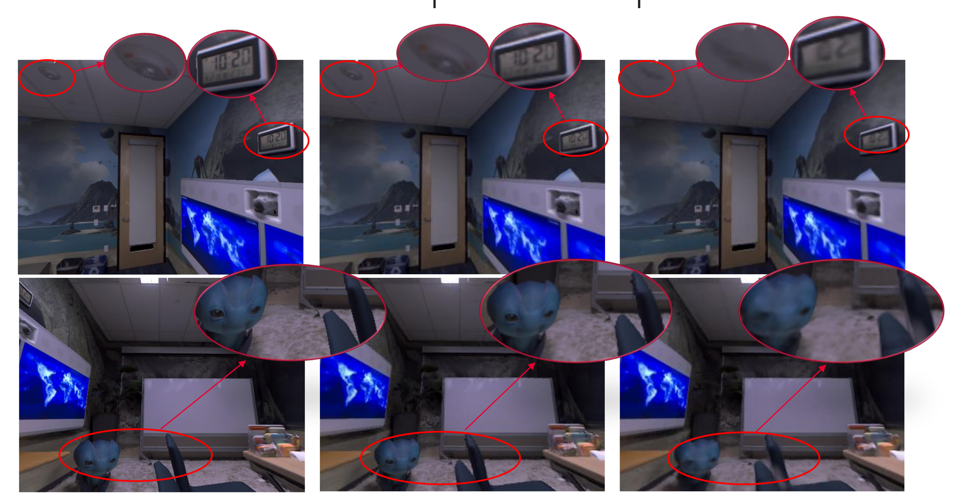
$$\lfloor_l x \rceil^h = \begin{cases} l, & x < l \\ x, & l \le x \le h \\ h, & x > h \end{cases}. \tag{10}$$

$$\mathcal{L}_d = \sqrt{\frac{1}{N_d}\sum_i g_i^2 + \frac{\lambda}{{N_d}^2}(\sum_i g_i)^2}, \tag{11}$$

Comparison Result

Performance	Efficiency		Color		Semantics		
Method	T_t	T_r	PSNR (dB)	SSIM	mIoU (%)	ACC_t (%)	ACC_a (%)
SS-NeRF	9 h	—	30.2	—	92.4	—	—
Semantic-NeRF	8 h	4.82 s	31.39	0.930	93.68	99.00	96.53
Ours	**15 min**	**0.1 s**	**35.9**	**0.970**	**94.79**	**99.29**	**97.68**

Performance	Geometry		
Method	AbsDiff	SqRel	RMSE
SS-NeRF	—	—	—
Semantic-NeRF	0.032	0.007	0.096
Ours	**0.0056**	**0.0006**	**0.0122**



GT ours Semantic-NeRF

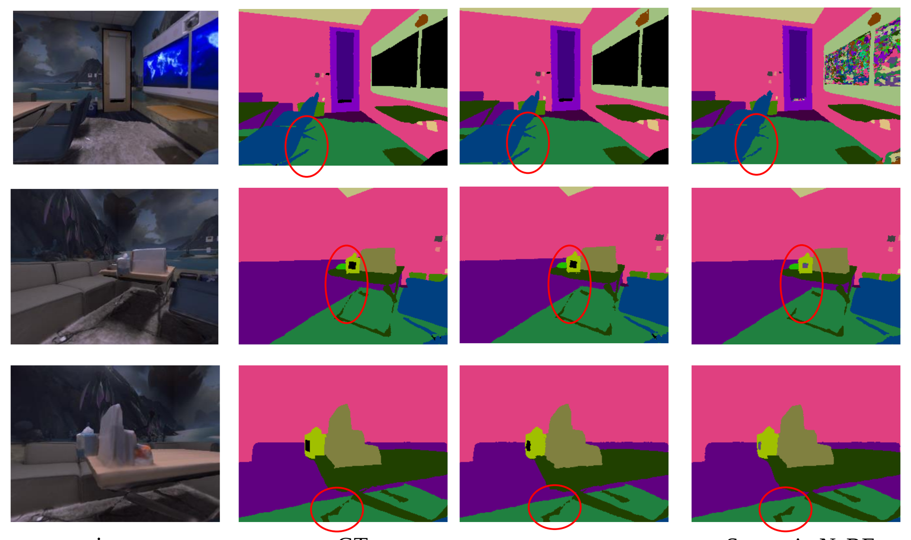
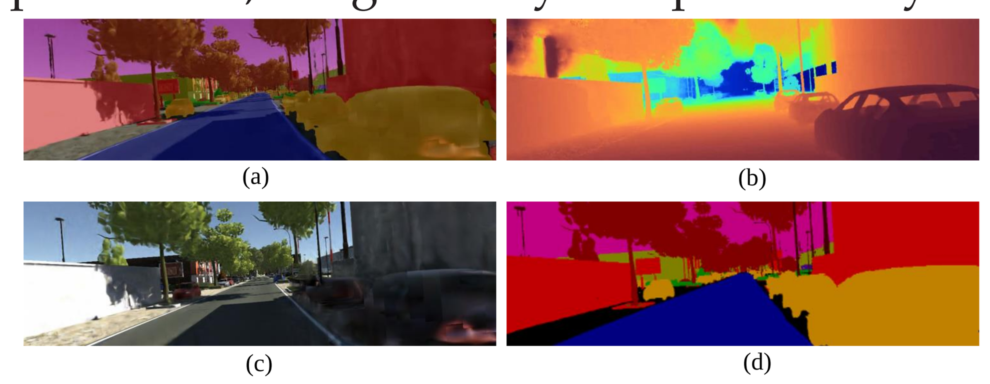


image GT ours Semantic-NeRF

Sparse View with Geometric Priors

For sparse view, the geometry is supervised by depth.



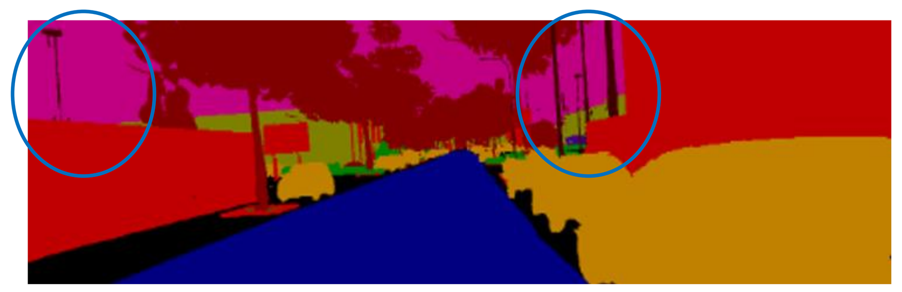
Robustness to Sparse Labels

The proposed IS-NEAR with point-to-surface global feature is robust to the sparse labels.

R	PSNR (dB)	SSIM	mIoU (%)	ACC_t (%)	ACC_a (%)
10%	40.7	0.989	93.1	99.1	96.1
20%	40.5	0.988	93.1	99.1	96.2
25%	40.3	0.988	92.4	99.0	96.2
50%	40.7	0.989	92.6	99.0	96.1
100%	40.6	0.989	92.3	99.0	95.9
10%w/o PS	39.6	0.985	83.6	97.3	91.0
20%w/o PS	39.1	0.983	89.3	98.5	94.5
25%w/o PS	39.1	0.982	89.4	98.6	94.6

Truncated-Weights Semantic Loss

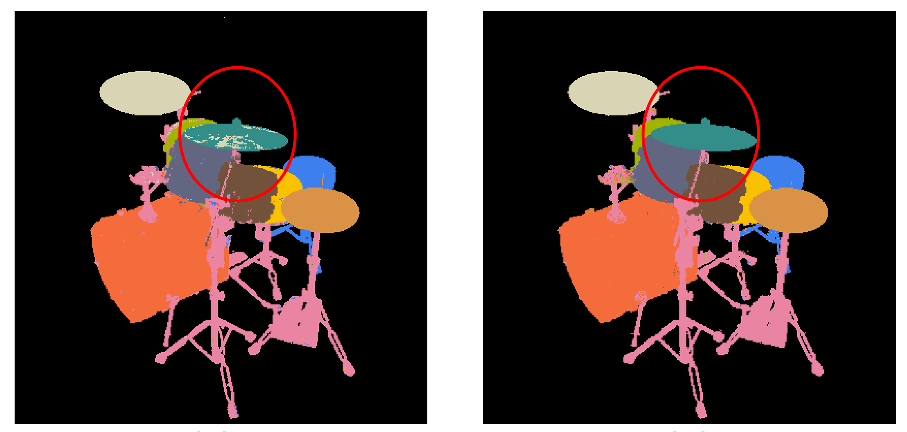
(a)



(b)

(a) Traditional cross-entropy loss
(b) Truncated-weights cross-entropy loss (Eq. 10)

Semantic Rendering without Direction Embedding

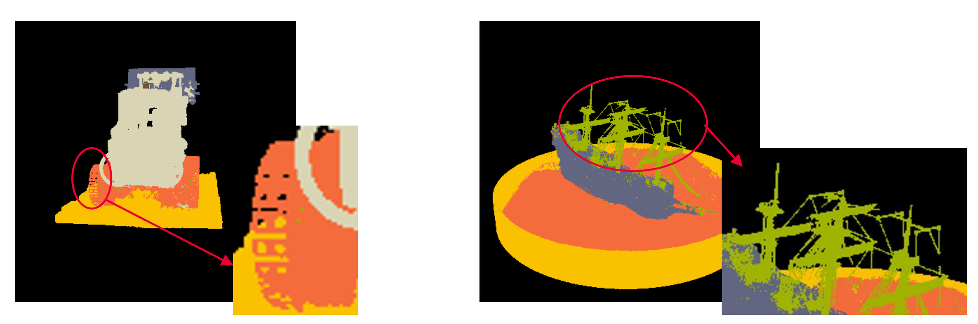


(a) (b)

(a) With direction embedding (b) Without direction embedding

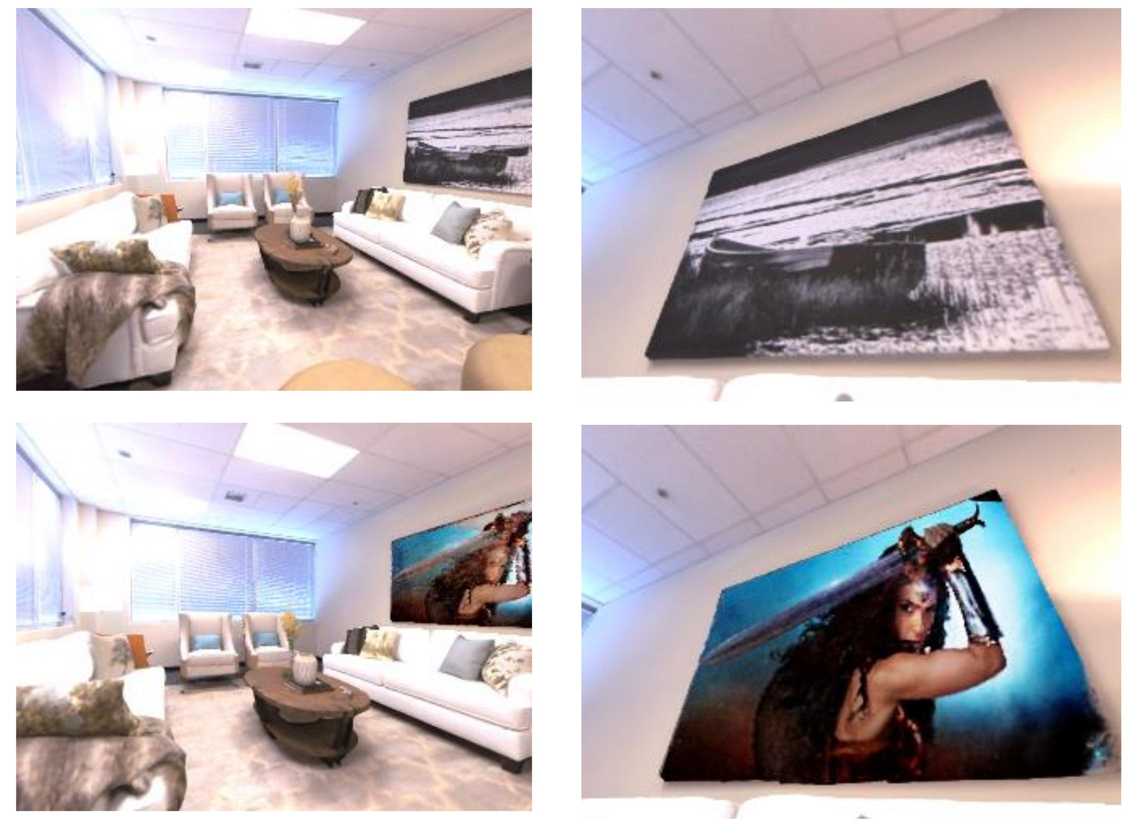
Application-Labeling

Input few coarse labels Output dense detailed labels



Rendering detailed semantics

Application-Texture Rerendering

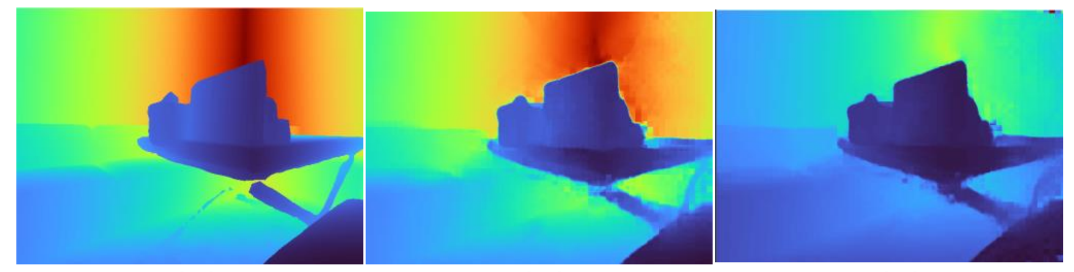


Update specific semantic region textures

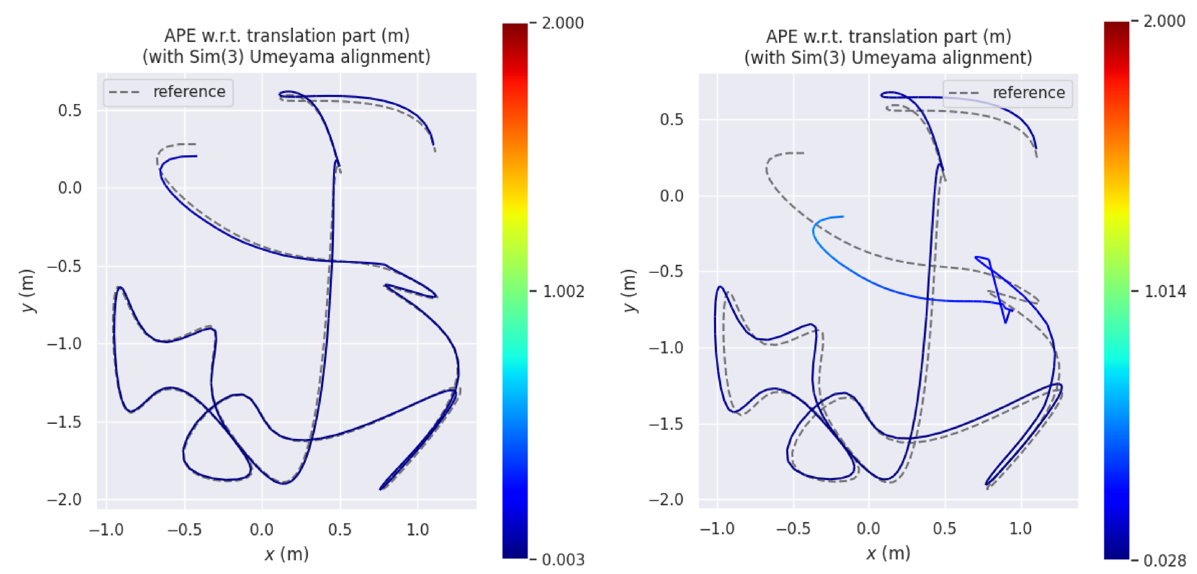
Application-Simulation

The monocular and binocular sequence data generated by IS-NEAR are used for SLAM simulation.

(a) (b)



(c) (d) (e)



stereo mono

For Paper, Results, Code and More

{suntiecheng1,lintao879,dongxingliang}@huawei.com
wei.zhang@ifp.uni-stuttgart.de