S^{3}E: Self-Supervised State Estimation for Radar-Inertial System

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Demo & Dataset
https://shengpeng.wang/s3e/

ICCV OCT 19-23, 2025 HONOLULU HAWAII

Overview

Background:
Achieve ***state estimation*** and ***landmark extraction*** in harsh conditions.

Traditional methods typically rely on post-processed radar point clouds, which are plagued by three issues:

- ◇ The inherent sparsity of radar point clouds from onboard processor
- ◇ 'Ghost points' from multi-path effects, speckle and saturation noise
- ◇ Low-angle resolution from a limited number of antennas

Self-Supervised State Estimator (S^{3}E) employs more ***richly informative*** radar signal spectra to bypass sparse points and explores complementary benefits from **exteroceptive** radar and **proprioceptive** inertial sensor to achieve accurate localization through **three key innovations**:

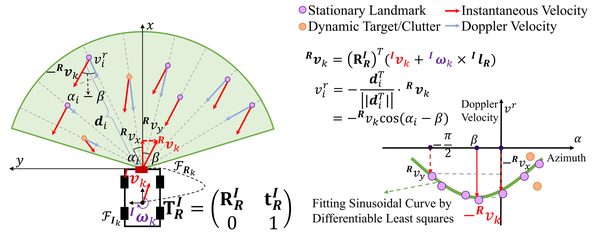
§ A novel self-supervised state estimator is proposed, which capitalizes on the **complementary perceptual** capabilities of RIS to achieve precise state estimation.

§ A novel Rotation-based cross-fusion is conceived to effectively **preserve motion-consistent features** and **enhance the spatial structure** across adjacent spectra.

§ The closed-loop **velocity alignment** and **angular alignment** are explored to render self-supervised learning feasible according to the spatial and Doppler domains.

Insight

Velocity Alignment:



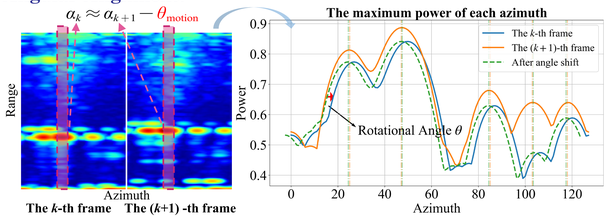
$$^{R}v_k = (R_R^I)^T({}^{I}v_k + {}^{I}\omega_k \times {}^{I}l_R)$$

$$v_i^r = -\frac{d_i^T}{||d_i^T||} \cdot {}^{R}v_k = -{}^{R}v_k \cos(\alpha_i - \beta)$$

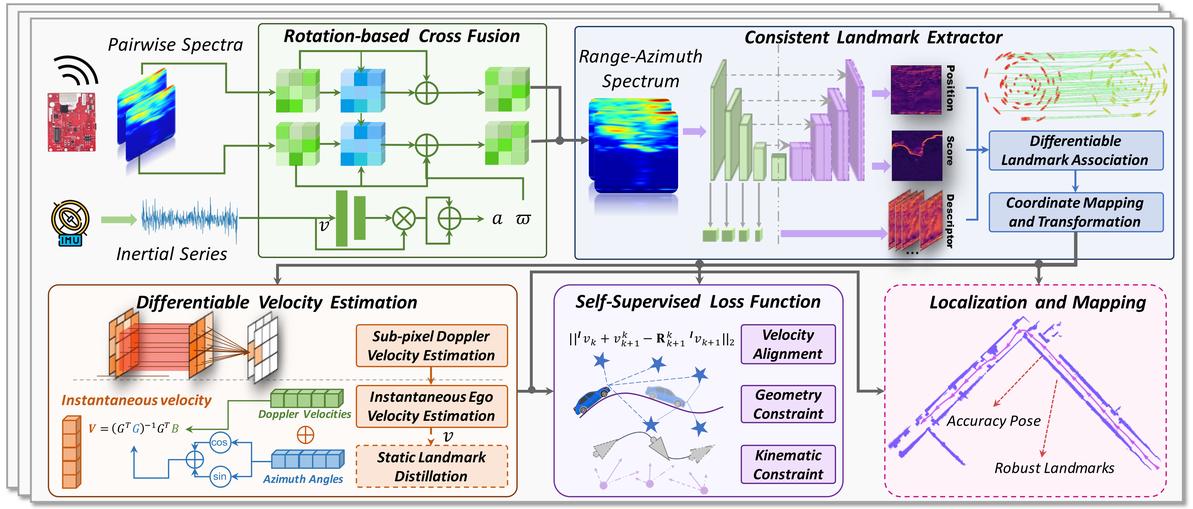
$$T_R^I = \begin{pmatrix} R_R^I & t_R^I \\ 0 & 1 \end{pmatrix}$$

Angular Alignment:

$$\alpha_k \approx \alpha_{k+1} - \theta_{motion}$$

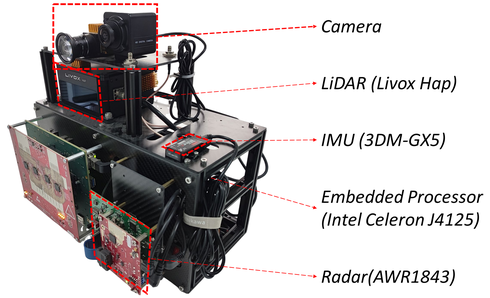


Spatial-Doppler Diffusion Model (SDDiff)

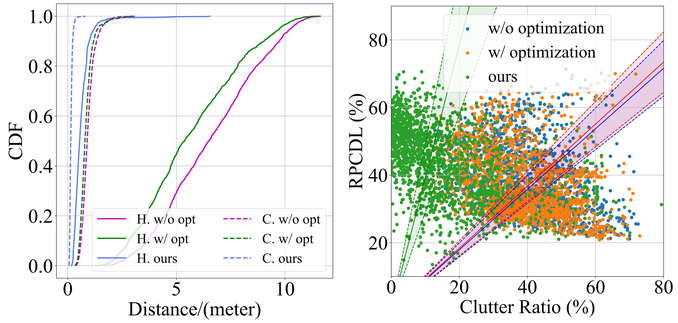


Experiments

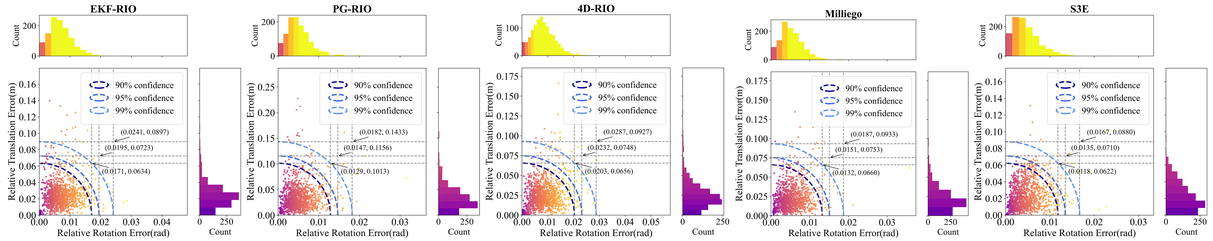
Data Collection Platform:

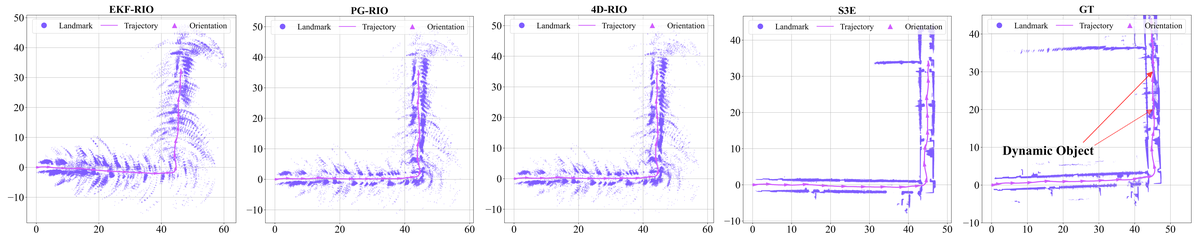


Quality Assessment of Landmark Extractor:



Error Distribution and Confidence Assessment:





Localization Performance Results:

Radar-based Localization Methods	indoor seq0		indoor seq1		indoor seq2		indoor seq3		outdoor seq0		outdoor seq1		outdoor seq2	
	Trans. ↓	Rot. ↓	Trans. ↓	Rot. ↓	Trans. ↓	Rot. ↓	Trans.	Rot. ↓	Trans. ↓	Rot. ↓	Trans. ↓	Rot. ↓	Trans. ↓	Rot.↓
EKF-RIO	-	-	5.32	6.08	4.65	5.61	5.68	**2.16**	6.19	5.38	6.90	11.3	9.73	19.1
PG-RIO	-	-	2.61	2.99	7.67	14.7	5.58	5.26	3.94	3.99	**2.31**	9.49	2.74	15.8
4D-RIO	-	-	5.62	2.56	8.37	4.69	5.91	4.33	4.97	3.01	2.55	12.1	2.48	18.2
Milliego	9.14	2.23	**2.32**	**1.91**	**2.02**	5.92	4.46	5.01	**2.13**	2.45	2.84	7.89	3.17	**11.0**
S^{3}E (Ours)	**5.69**	**2.07**	2.45	2.21	2.16	**3.83**	**3.90**	2.53	2.33	**2.11**	2.82	**4.28**	**2.34**	11.3

Contact:

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