PhD Open Days

Proactive Feature Quality Assessment for LiDAR-Inertial Odometry Using Physical Signal Analysis

Institute for Systems and Robotics | LISBOA

Read the ICARSC 2026 paper →

PhD in Electrical and Computer Engineering

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Not every LiDAR point deserves the same trust.

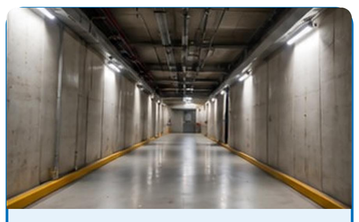
ABSTRACT LiDAR–inertial odometry (LIO) keeps UAVs localized where GPS is unreliable, but degrades when the scanned geometry is weak, repetitive or non-rigid, because most estimators treat all measurements as equally reliable.
Research question: how can LIO account for the reliability of each measurement?
C1 (IEEE ICARSC 2026) scores every point from photometric stability, planarity and range before the IEKF update of FAST-LIO2: 63.1% lower median APE on MARS-LVIG Featureless at +4.0% runtime.
C2 (in preparation) adds intensity as a measurement through a calibration-free photometric layer for LM and IEKF back-ends: on 8 sequences it reduces failures for all three back-ends and analyzes when intensity harms.



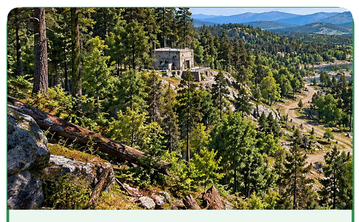
1 Where LIO loses reliable constraints



Feature-poor terrain
- few distinctive 3D structures
- some motion directions become weakly observable



Repetitive / symmetric
- tunnels, corridors, repeated structures
- several alignments look plausible



Dense vegetation
- many returns, not all reliable
- leaves and thin branches move between scans

⚠ **Failure cycle:** unreliable measurements → weak correction → growing pose uncertainty → inconsistent map → degraded planning

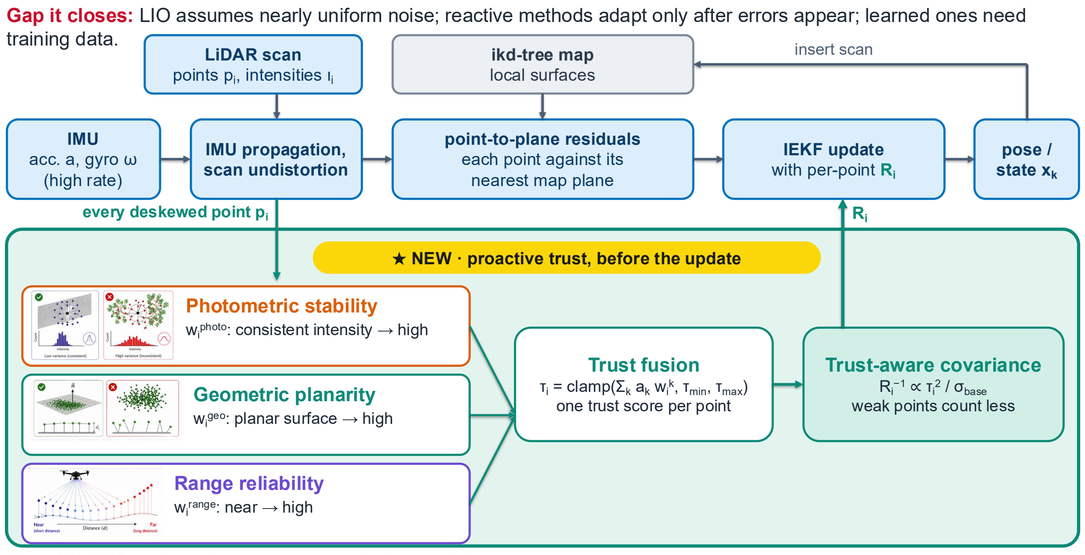
2 C1 · Proactive per-point trust

IEEE ICARSC 2026

★ NOVELTY **A proactive, physics-based reliability model for every LiDAR point, inside the LIO filter: trust is judged before the update, with no training data and +4.0% runtime.**

- ✓ **Proactive** – before the update
- ✓ **Training-free** – intensity, geometry, range
- ✓ **Per-point covariance** – not one noise level
- ✓ **Drop-in** – inside FAST-LIO2

Gap it closes: LIO assumes nearly uniform noise; reactive methods adapt only after errors appear; learned ones need training data.



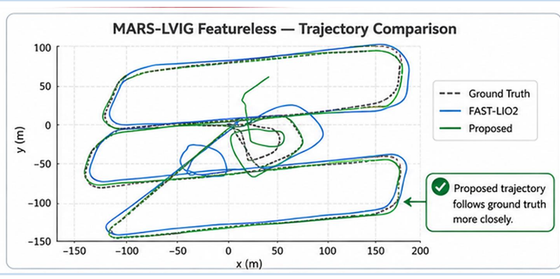
blue: FAST-LIO2, unchanged · green: our proactive trust module (new) · grey: map

EXPERIMENTAL SETUP



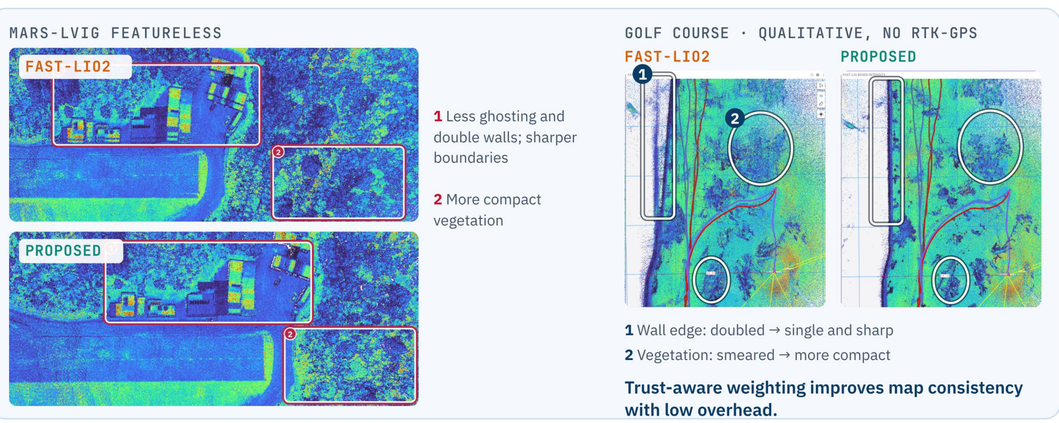
- **C1, two datasets:** (i) MARS-LVIG Featureless [3]: public UAV sequence, Livox Avia, RTK-GPS ground truth → trajectory accuracy and runtime; (ii) golf course: our UAV, ≈300 m over dense vegetation, no RTK-GPS under the canopy → qualitative map consistency.
- **C2:** 8 sequences from five datasets: ENWIDE [4], Newer College [7], GEODE [8], MARS-LVIG [3] and our UAV (a flight with a restricted field of view), recorded with three LiDARs: Ouster OS0-128, Livox Avia, Livox Mid-360.

3 C1 · Experiments and results



−63.1%
median APE vs FAST-LIO2 (RTK-GPS truth)

+4.0%
runtime overhead

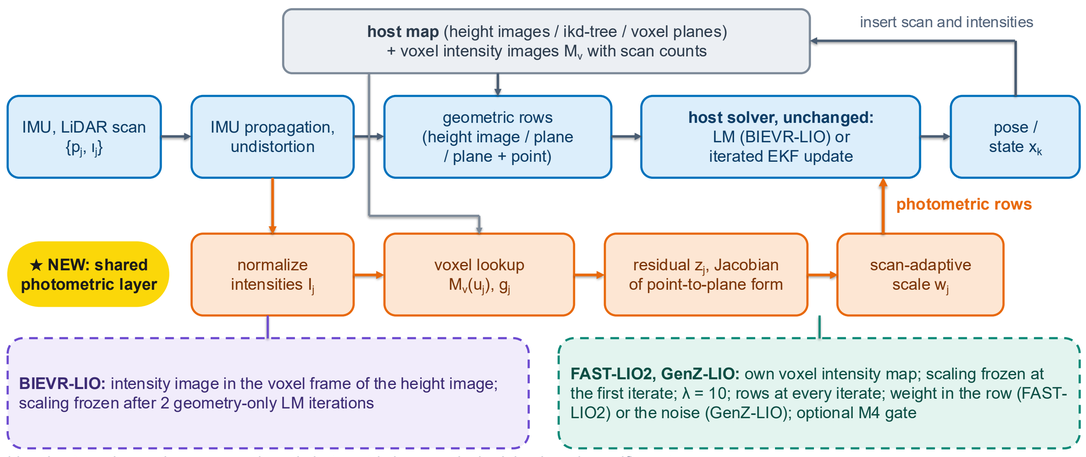


Trust-aware weighting improves map consistency with low overhead.

4 C2 · Portable photometric layer

IN PREPARATION

★ NOVELTY **One calibration-free photometric layer that plugs into both optimization (LM) and filtering (IEKF) LIO back-ends, with an analysis of when intensity helps and when it harms.**



blue: host, unchanged · orange: shared photometric layer · dashed: back-end-specific parts · grey: maps

Sequence	Data	BIEVR-LIO (LM)		COIN-LIO	FAST-LIO2 (IEKF)		GenZ-LIO (IEKF)	
		stock	+ layer		stock	+ layer	stock	+ layer
TunnelD	ENWIDE	×	**0.276**	0.492	×	**0.380**	×	**0.442**
TunnelS	ENWIDE	×	**0.660**	0.780	×	**1.020**	×	×
RunwayD	ENWIDE	4.365	**0.308**	3.542	×	**3.134**	×	**3.525**
Featureless	MARS-LVIG	3.734	3.648	–	28.9	**3.751**	3.574	3.574
HKairport	MARS-LVIG	×	**1.605**	–	0.922	**0.862**	1.005	**0.895**
Custom-1 FOV30	Ours (UAV)	5.011	**0.643**	–	×	**3.123**	×	**0.609**
Stairs	Newer C.	0.056	0.056	0.219	0.200	×	0.123	**0.096**
Offroad4	GEODE	0.658	0.652	–	0.675	13.8	0.714	×
Failures	8 seq.	**3/8**	**0/8**	**0/4**	**4/8**	**1/8**	**4/8**	**2/8**

ATE RMSE [m] after SE(3) alignment; × failure (divergence or ATE > 5 % of path); – not evaluated (COIN-LIO runs on Ouster data only: 4 of the 8 sequences). Green / red: the layer rescues or improves (> 5 %) / fails or degrades the same back-end.

5 CONCLUSIONS

C1 · published
Assessing per-point reliability before the IEKF update lowers the median APE by 63.1% relative to FAST-LIO2 on MARS-LVIG Featureless, at +4.0% runtime and without training data.

C2 · in preparation
One calibration-free photometric layer serves both LM and IEKF back-ends: failures fall from 3 to 0 of 8 sequences (BIEVR-LIO) and from 4 to 1 and 4 to 2 of 8 (FAST-LIO2, GenZ-LIO).

Next
reliability-aware mapping (RQ2) and belief-aware planning (RQ3).

[1] N. Khosravi, R. Ventura, and M. Basiri, "Proactive feature quality assessment for LiDAR-inertial odometry using physical signal analysis," in Proc. IEEE Int. Conf. Autonomous Robot Systems and Competitions (ICARSC), Barcelos, Portugal, 2026, pp. 138–144, doi: 10.1109/ICARSC70216.2026.11523258.
[2] W. Xu, Y. Cai, D. He, J. Lin, and F. Zhang, "FAST-LIO2: Fast direct LiDAR-inertial odometry," IEEE Trans. Robot., vol. 38, no. 4, pp. 2053–2073, 2022.
[3] H. Li et al., "MARS-LVIG dataset: A multi-sensor aerial robots SLAM dataset for LiDAR-visual-inertial-GNSS fusion," Int. J. Robot. Res., vol. 43, no. 8, pp. 1114–1127, 2024.
[4] P. Pfreundschuh, H. Oleynikova, C. Cadena, R. Siegwart, and O. Andersson, "COIN-LIO: Complementary intensity-augmented LiDAR inertial odometry," in Proc. IEEE Int. Conf. Robot. Autom. (ICRA), 2024, pp. 1730–1737.
[5] P. Pfreundschuh et al., "BIEVR-LIO: Robust LiDAR-inertial odometry through bump-image-enhanced voxel maps," in Proc. Robotics: Science and Systems (RSS), 2026, arXiv:2604.14421.
[6] D. Lee et al., "GenZ-LIO: Generalizable LiDAR-inertial odometry beyond confined-open boundaries," arXiv:2603.16273, 2026.
[7] L. Zhang, M. Camurri, D. Wisth, and M. Fallon, "Multi-camera LiDAR inertial extension to the Newer College dataset," arXiv:2112.08854, 2021.
[8] Z. Chen et al., "Heterogeneous LiDAR dataset for benchmarking robust localization in diverse degenerate scenarios," Int. J. Robot. Res., vol. 45, no. 1, pp. 6–22, 2026.

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