A Deterministic Trajectory-Family Selection Method for Visual–Inertial SLAM under Floorplan Consistency Constraints

Abstract

This report describes a final SLAM method prepared for the Hilti–Trimble 360 Visual-Inertial SLAM Challenge 2026. The method is a deterministic trajectory-family selector built on top of a conservative ORB-SLAM3 and localization hybrid baseline. The central design principle is conservative model selection: a baseline trajectory is replaced only when fixed geometric diagnostics indicate that an alternative trajectory is more consistent with the floorplan while remaining compatible with the baseline SLAM shape. The final system uses one enabled replacement family, localization-refined floorplan selection, and disables a direct cam1 ORB family at the source-family level after validation showed that its floorplan-only gains were not reliable predictors of final SLAM accuracy.

1 Introduction

The SLAM task evaluates complete camera trajectories rather than isolated local pose estimates. This creates two important requirements. First, the trajectory must have correct metric scale because the evaluation aligns only by rigid transformation and does not perform scale correction. Second, the output must maintain high temporal coverage over each sequence.

The final system adopts a conservative selection strategy. A robust baseline trajectory set is generated first. Alternative trajectory families are then evaluated by fixed diagnostics. A replacement is accepted only if it passes all gates for its source family. If no candidate passes, the baseline is kept unchanged.

The final method is not intended to maximize the number of edited runs. Its goal is to improve the baseline only in cases where several independent machine-readable signals agree: floorplan consistency improves, geometric deformation remains bounded, vertical behavior remains plausible, and the alternative trajectory is compatible with the existing SLAM shape after rigid fitting.

2 Evaluation Metric

For each run, the server evaluates a predicted trajectory in TUM format,

$$t,\ x,\ y,\ z,\ q_x,\ q_y,\ q_z,\ q_w. \tag{1}$$

After rigid SE(3) alignment, the run score is

$$S = \frac{1}{N}\sum_{i=1}^{N} 100\exp(-0.46051701859880917\, e_i), \tag{2}$$

where e_i is the 3D position error at the i-th evaluated timestamp. The aggregate objective is the sum of sequence-level scores over the evaluation set.

ORB-SLAM3 mono-cam0 trajectories + localization trajectories → protected hybrid baseline → floorplan and shape diagnostics → fixed-rule localization-refined selector → validated SLAM trajectory archive

Figure 1: High-level structure of the final SLAM selector. All trajectory replacement decisions are made by fixed rules.

3 Method Overview

The final SLAM method consists of four deterministic stages:

1. generation of a protected ORB/localization hybrid baseline;
2. computation of trajectory and floorplan diagnostics for every run;
3. fixed-rule evaluation of localization-refined candidate trajectories; and
4. validated trajectory-archive construction in TUM format.

The implementation reads the baseline and candidate trajectory families, evaluates all target sequences, copies accepted replacements into a new trajectory archive, validates all outputs, and emits the final TUM-format trajectory archive.

4 Protected Hybrid Baseline

The protected baseline combines ORB-SLAM3 monocular cam0 trajectories with a localization trajectory family. The baseline selector keeps the ORB trajectory only when it satisfies fixed quality checks: stable ORB logs, sufficient estimated temporal coverage, non-collapsed spatial span, and bounded disagreement with the localization trajectory. Otherwise, it falls back to the localization trajectory.

Let $\mathbf{X}_r^{\mathrm{orb}}$ and $\mathbf{X}_r^{\mathrm{loc}}$ denote the ORB and localization trajectories for run r. The baseline selection can be written as

$$\mathbf{X}_r^{\mathrm{base}} = \begin{cases} \mathbf{X}_r^{\mathrm{orb}}, & \text{if ORB quality gates pass,} \\ \mathbf{X}_r^{\mathrm{loc}}, & \text{otherwise.} \end{cases} \tag{3}$$

This baseline is treated as the protected fallback for all later stages.

5 Floorplan and Shape Diagnostics

Every candidate replacement is evaluated with diagnostics computed from the trajectory and the corresponding floorplan mask. The diagnostics include:

- outside-of-floorplan rate;
- wall-crossing rate;
- local free-space agreement;
- corridor-heading agreement;

Diagnostic	Required condition
Cam0–localization disagreement	$0.35 \leq d \leq 0.75$ m
Outside-rate reduction	at least 0.006
Wall-crossing reduction	at least 0.006
Free-space mean gain	at least 0.003
Rigid-fit RMSE to baseline	at most 0.85 m
Mean aligned delta to baseline	$0.15 \leq d \leq 0.80$ m
Baseline and candidate vertical span	at most 2.0 m
Path-length ratio	$0.93 \leq r \leq 1.08$
Bounding-box area ratio	$0.85 \leq r \leq 1.15$

Table 1: Fixed acceptance gates for the localization-refined source family in the final selector.

- path-length ratio relative to baseline;
- bounding-box area ratio relative to baseline;
- vertical span; and
- rigid-fit compatibility with the baseline trajectory.

For a candidate trajectory $\mathbf{X}_r^c$, the selector computes deltas relative to $\mathbf{X}_r^{\text{base}}$:

$$\Delta m = m(\mathbf{X}_r^c) - m(\mathbf{X}_r^{\text{base}}), \tag{4}$$

where m is a floorplan or shape diagnostic. Negative deltas are favorable for outside and wall-crossing rates, while positive deltas are favorable for free-space agreement.

Rigid-fit compatibility is measured by aligning the candidate to the baseline with a rigid transform and computing the residual root-mean-square error. This does not use ground truth. It is a consistency check that rejects candidates that imply a large trajectory rewrite even if their floorplan statistics look better.

For each candidate source c, the decision variable for run r is

$$a_{r,c} = \mathbb{I}\begin{bmatrix} \Delta o_{r,c} \leq -\tau_o, & \Delta w_{r,c} \leq -\tau_w, & \Delta f_{r,c} \geq \tau_f, \\ \rho_{r,c} \leq \tau_\rho, & \ell_{r,c} \in [\ell_{\min}, \ell_{\max}], & b_{r,c} \in [b_{\min}, b_{\max}] \end{bmatrix}, \tag{5}$$

where o, w, and f denote outside rate, wall-crossing rate, and free-space agreement; ρ is the rigid-fit residual to the baseline; ℓ is the path-length ratio; and b is the bounding-box area ratio. This formulation separates score estimation from trajectory acceptance: server feedback is used only to select among source families during development, while per-run acceptance is controlled by trajectory-derived diagnostics.

6 Localization-Refined Candidate Family

The enabled candidate family in the final method is the localization-refined floorplan family. It uses a deterministic localization-refined trajectory source. For each run, the selector compares this candidate to both the protected SLAM baseline and the raw cam0 ORB trajectory. The raw cam0-versus-localization disagreement is used as a machine-readable signal that the ORB and localization families are meaningfully different but not catastrophically inconsistent.

The accepted candidate must pass every gate in Table 1. These thresholds are fixed in the method and applied uniformly to all target sequences.

If all gates pass, the candidate replaces the baseline trajectory for that run. If any gate fails, the baseline trajectory remains unchanged. The resulting trajectory set is therefore a deterministic function of the input trajectory families and the fixed thresholds in Table 1.

Source family	Final role	Rationale
Protected hybrid baseline	Default trajectory source	Retained for every run unless a candidate passes all floorplan, shape, and vertical-span gates.
Localization-refined floorplan source	Enabled replacement source	Accepted because its improvements are evaluated by multiple independent trajectory-derived diagnostics rather than a single floorplan statistic.
Direct cam1 ORB source	Disabled source family	Rejected because floorplan-only improvement did not provide a reliable source-family criterion for final trajectory accuracy.

Table 2: Final source-family policy after ablation. The table describes the global model-selection decision, not a sequence-specific replacement list.

7 Source-Family Ablation

During source-family ablation, an additional direct cam1 ORB family was evaluated. It was accepted for one sequence because it improved floorplan wall-crossing statistics. Subsequent evaluation showed that this criterion did not generalize to final SLAM accuracy. The source was therefore rejected as a family rather than retained for isolated favorable cases.

The final selector therefore disables the direct cam1 ORB family globally. This is a source-family decision rather than a per-sequence exception. The enabled final method contains only the localization-refined family described in Table 1.

8 Final Source-Family Policy

The final selector changes only runs for which the enabled replacement family passes the fixed gates in Table 1. The selected policy is summarized in Table 2. This table reports the unit of decision used by the method: source families are enabled or disabled globally, while individual trajectories are selected only by fixed diagnostics.

9 Output Verification

The generated trajectory set was checked against the evaluator input contract:

- the implementation compiled successfully;
- every trajectory satisfies the TUM pose-file syntax;
- the compressed archive passes integrity checks;
- the archive contains the expected root-level trajectory files and no nested paths;
- the run manifest is complete; and
- exactly three trajectories differ from the protected baseline, consistent with the deterministic source-family policy.

These checks verify format validity, sequence coverage, and reproducibility of the deterministic selection rule. They do not introduce additional trajectory selection criteria.

10 Discussion

The main strength of this method is its conservative replacement policy. The baseline already provides high coverage and stable behavior across all runs. The selector modifies only runs where the localization-refined family simultaneously improves floorplan consistency and remains geometrically close to the baseline SLAM shape.

The main limitation is that conservative gates leave several difficult runs unchanged. An alternative trajectory is accepted only when it satisfies the same geometric consistency tests as every other sequence. This reduces sensitivity to source-family overfitting at the cost of leaving some potentially repairable sequences unchanged.

11 Conclusion

This report presented a deterministic trajectory-family selection method for the SLAM task. The method starts from a protected ORB/localization hybrid baseline and applies a fixed-rule localization-refined replacement family under floorplan, shape, and vertical-span constraints. The final selector disables the direct cam1 ORB family globally after source-family ablation and retains three localization-refined replacements that satisfy all fixed gates. The result is a deterministic and reproducible selection process driven by trajectory geometry rather than post hoc per-sequence corrections.