ROMAN: Robust Object Map Alignment Anywhere

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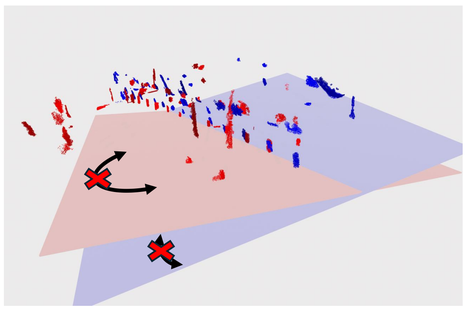
Motivation

Goal: view invariant and communication efficient global localization by aligning object maps

Challenge: Object locations alone can lead to ambiguous and incorrect map registration

- Geometric aliasing → wrong object associations
- Incorrect rotation in yaw (~180 degrees)
- Large roll/pitch angle



Alignment using only object centroids

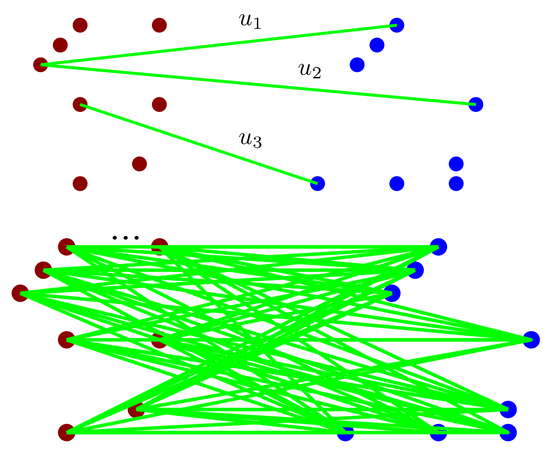
Background

Point registration using robust graph-theoretic data association

$$\max_{\mathbf{u}\in\{0,1\}^n} \frac{\mathbf{u}^\top \mathbf{M}\mathbf{u}}{\mathbf{u}^\top\mathbf{u}}$$

$$\text{s.t.} \quad u_p u_q = 0$$

$$\text{if } \mathbf{M}_{p,q} = 0,\ \forall_{p,q}$$



- Association vector, **u**
- Affinity matrix, **M**: association consistencies (pairwise distance similarity)

Approach

Incorporate gravity, semantic and shape information in the affinity matrix, **M:**

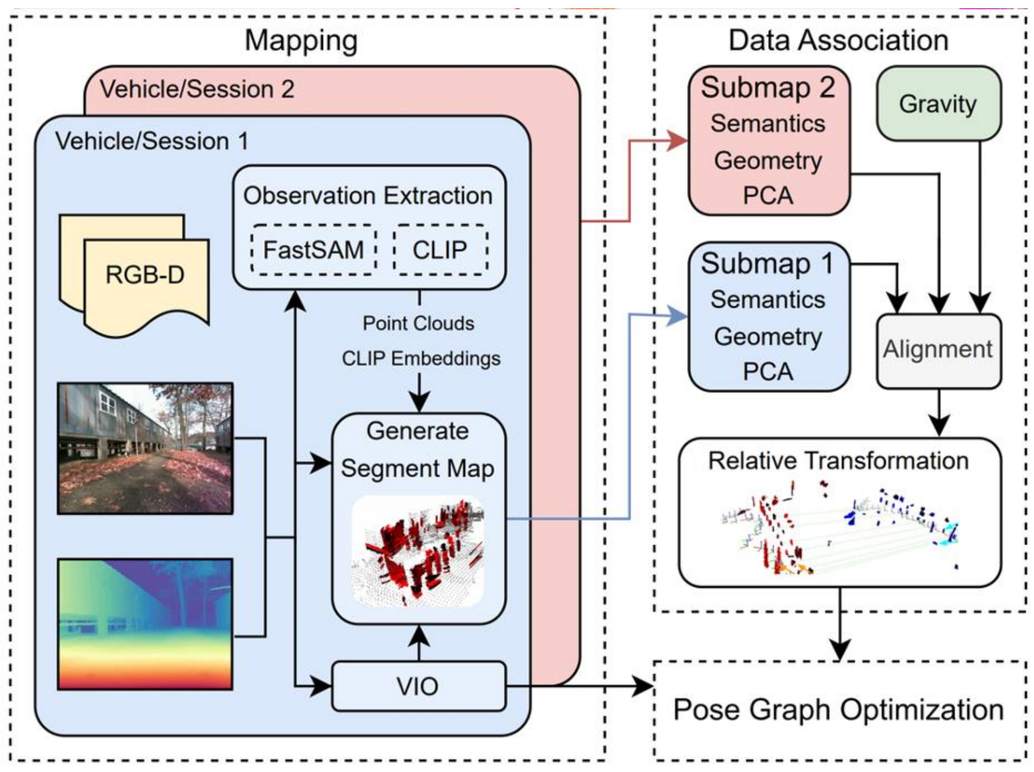
$$\mathbf{M}_{p,q} = \mathrm{GM}(s_a(a_p, a_q), s_o(a_p), s_o(a_q))$$

Associations *p* and *q* object **similarity** score:

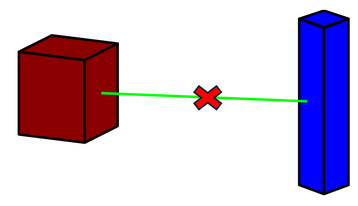
$$s_o(a_p) = \mathrm{GM}(s_{o_{\text{semantic}}}, s_{o_{\text{shape}}})$$

Gravity-guided pairwise score:

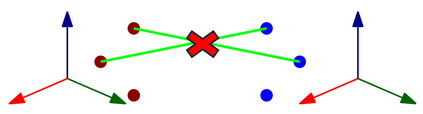
$$s_a(a_p, a_q)$$



Using **gravity direction** and **object shape and semantic information** to guide object association improves map alignment



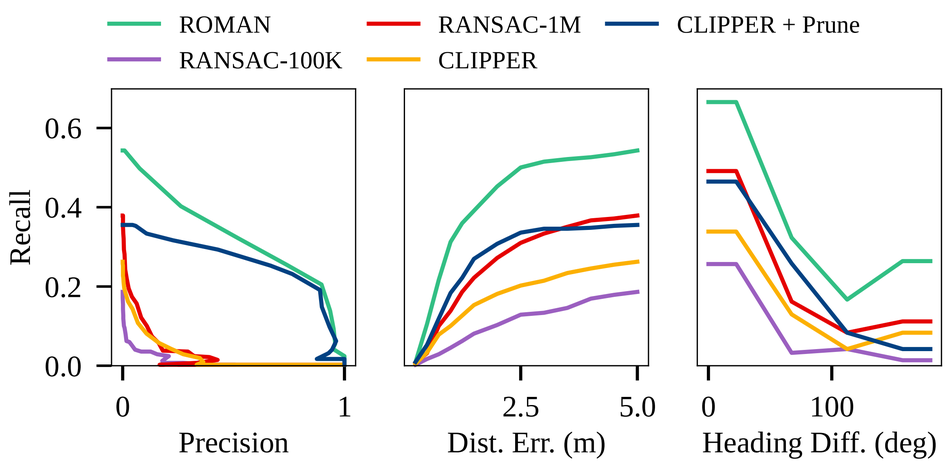
shapes are inconsistent



associations are inconsistent (z-axes are misaligned)

Global Localization Results

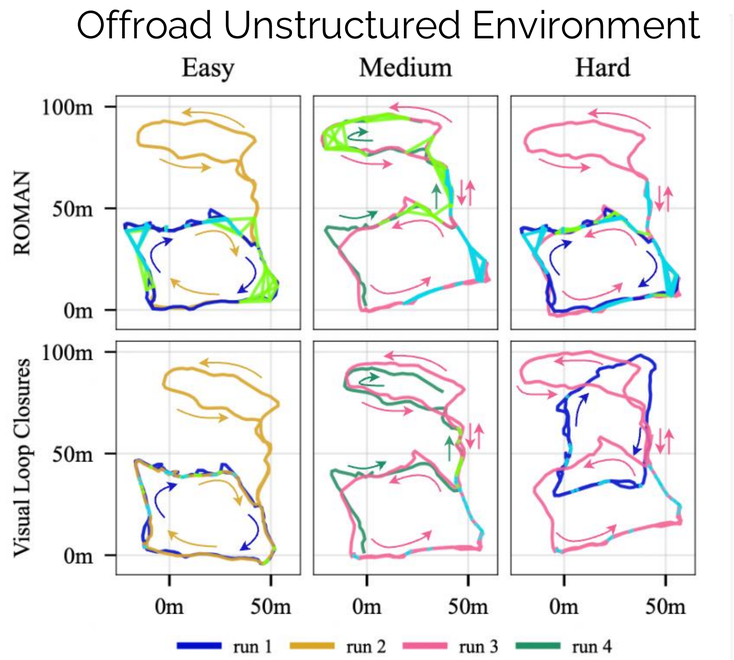
On MIT's campus, ROMAN achieves higher **precision and recall** than baselines, aligns maps with less error, and has greater **alignment success** in challenging opposite-view alignment cases



Kimera Multi Outdoor Dataset

SLAM Results

In an outdoor off-road environment with high visual ambiguity, ROMAN detects more **loop closures** than Kimera-Multi using visual features



Dataset	Visual Features	ROMAN	Combined
Tunnel	4.38	4.20	4.12
Hybrid	5.83	5.12	4.77
Outdoor	9.38	8.77	7.77

Kimera Multi Dataset

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[1] P. C. Lusk and J. P. How, "CLIPPER: robust data association without an initial guess," *IEEE RA-L*, 2024.
[2] Y. Tian et al., "Resilient and distributed multi-robot visual SLAM: Datasets, experiments, and lessons learned," in *IEEE/RSJ IROS*, 2023.