Shape Your Ground: Refining Road Surfaces Beyond Planar Representations

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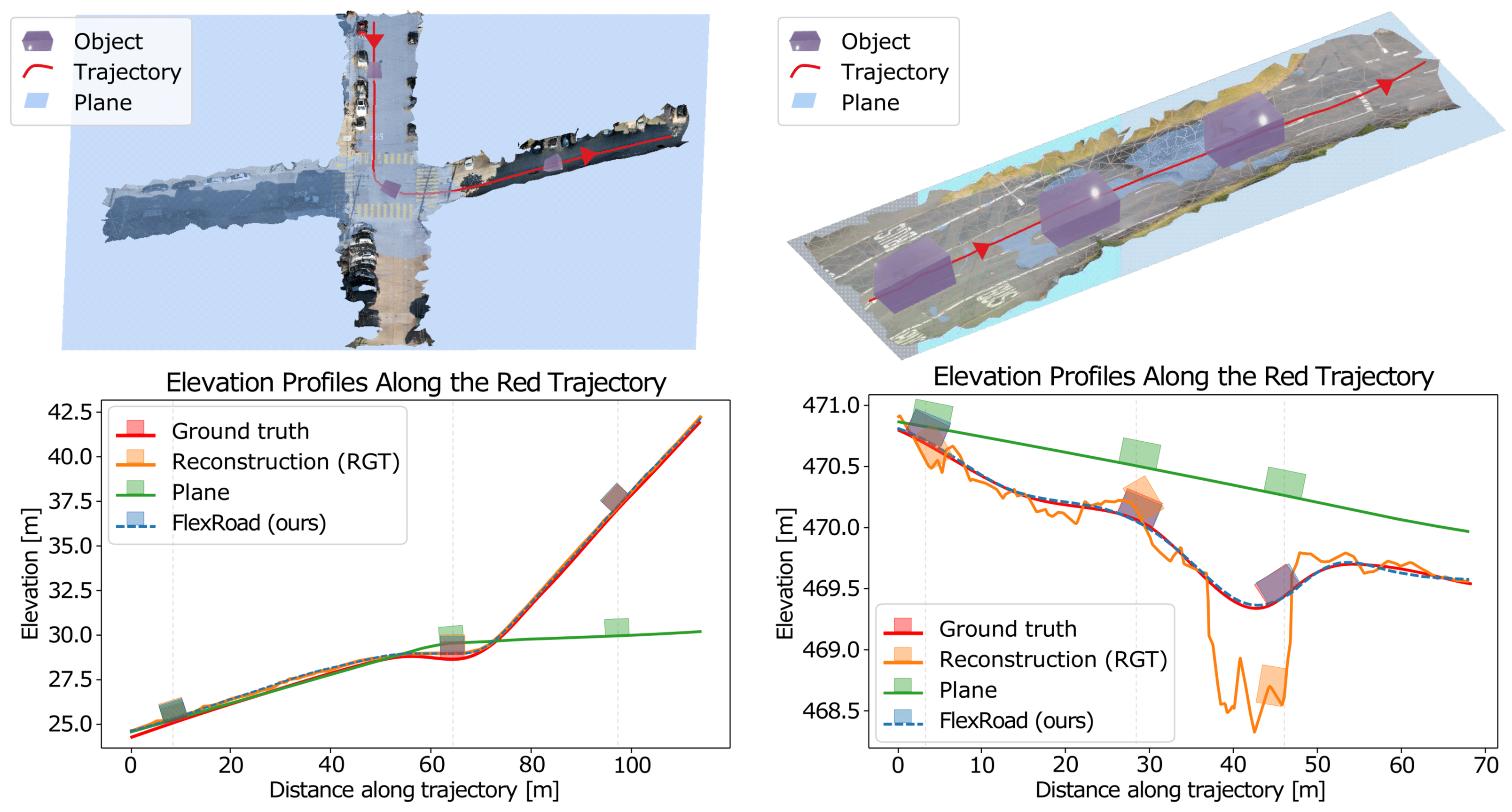
Overview

Problem

Road surface reconstruction from aerial images suffers from **artifacts**, **bumps**, and **holes**. Applications requiring road models either:

- Use **noisy** reconstructions directly.
- Oversimplify with **planar approximations**.



Road surface profiles: Raw reconstruction (orange) shows artifacts, planar approximation (green) oversimplifies, our method (blue) provides smooth accuracy.

Why It Matters?

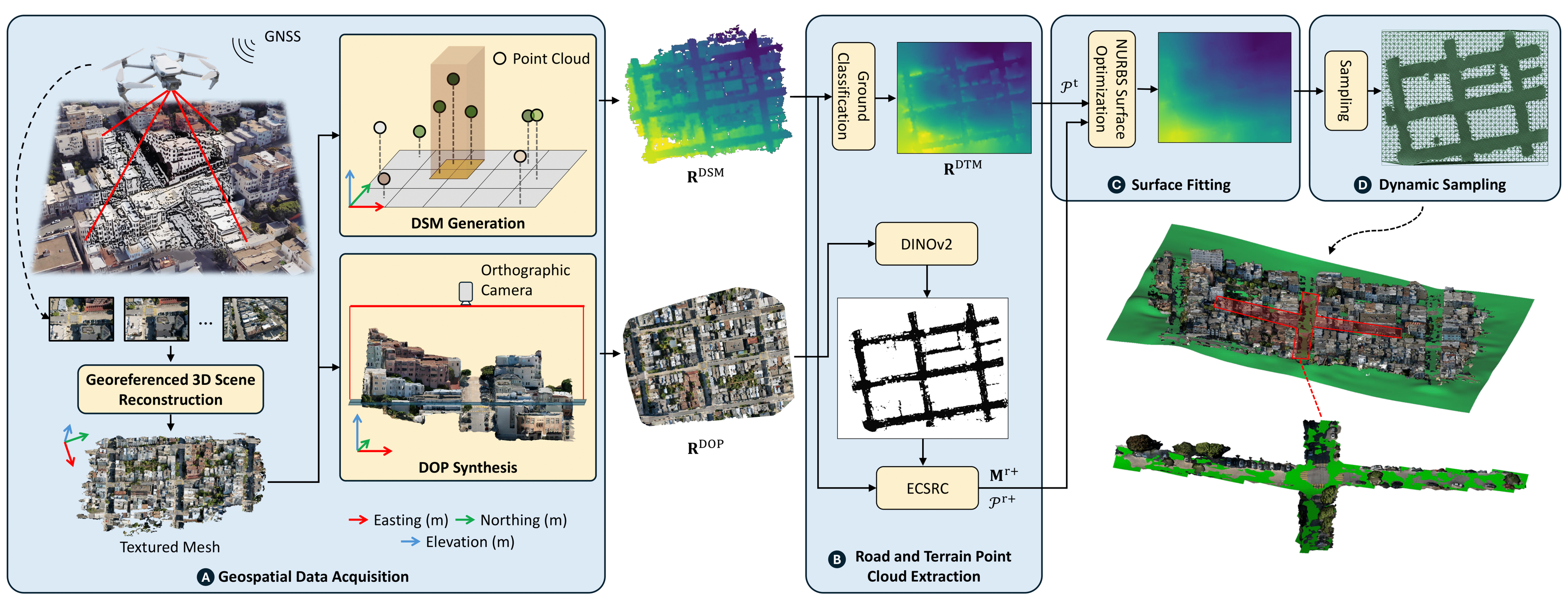
Smooth, **accurate** road surfaces are critical for:

- **Autonomous driving** (object detection & tracking).
- **Urban planning** and **infrastructure inspection.**
- **Virtual simulation** and **city modeling.**

Our Solution: FlexRoad

FlexRoad bridges the gap between geometric accuracy and surface smoothness for practical road modeling

Method



Our 4-stage workflow from data acquisition to final road mesh.

Stage A: Data Acquisition

- Input: Aerial images → Output: Digital Surface Model (DSM) and Digital Orthophoto (DOP) via photogrammetry or direct data download from geoportals.

Stage B: Road Extraction & Filtering

- **DINOv2 segmentation** identifies road masks.
- **Our Elevation-Constrained Spatial Road Clustering (ECSRC) Algorithm** : First road-specific noise removal (facades, trees, vehicles) that is based on region-growing combining spatial connectivity with elevation consistency.

Stage C: NURBS Surface Fitting

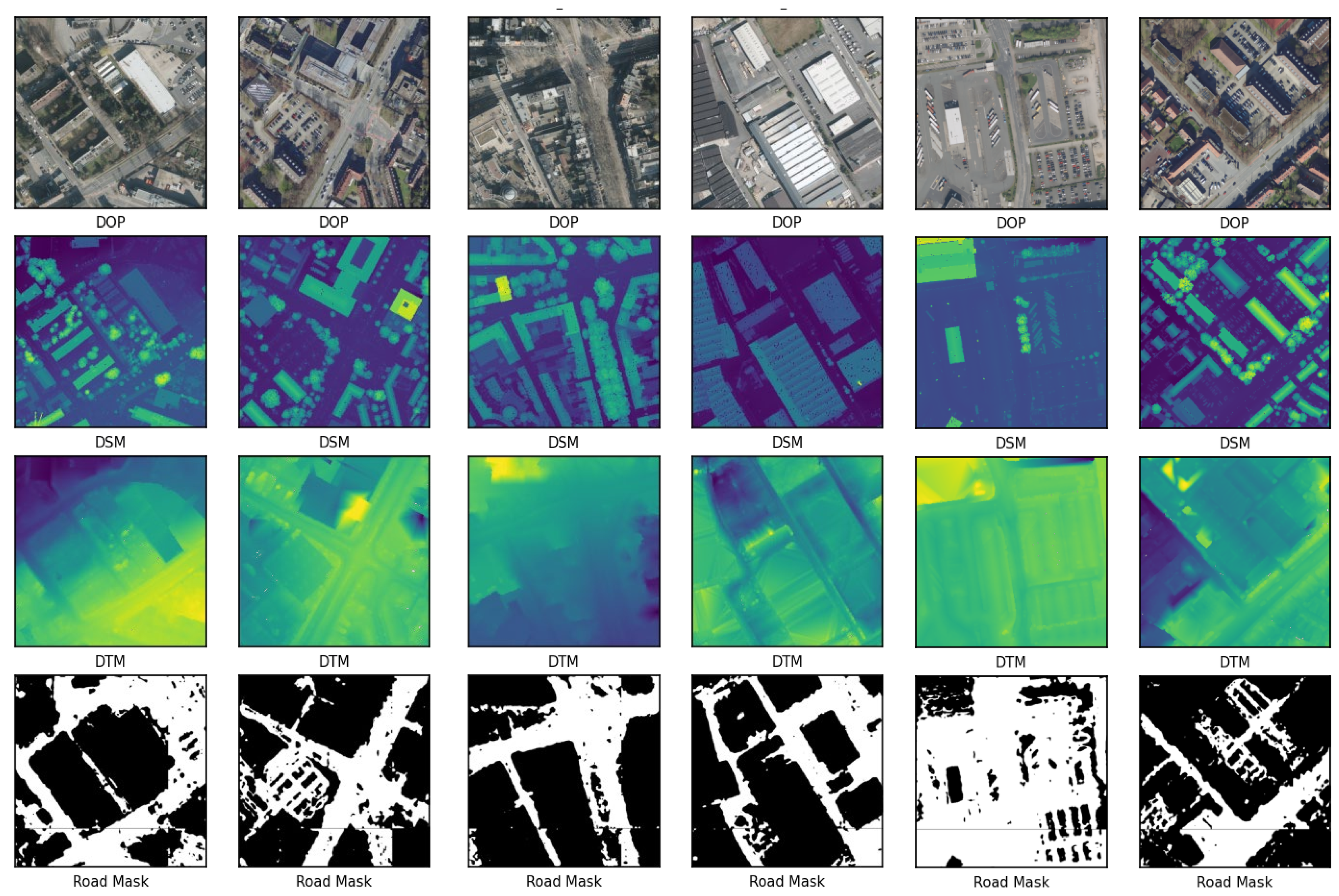
- Fitting a smooth Non-Uniform Rational B-Splines (NURBS) [3] with **tri-objective optimization**: road fitting, terrain fitting, and elevation regularization.

Stage D: Dynamic Sampling

- **Adaptive resolution**: combining high-resolution meshes for roads and low-resolution meshes for terrain using road masks and Delaunay triangulation [2].

GeRoD Dataset

14.5M LiDAR points | 240 Locations | 54.7m avg. elevation variation



GeRoad Dataset Samples.

GeRoad is the first standardized benchmark for 3D road surface reconstruction evaluation

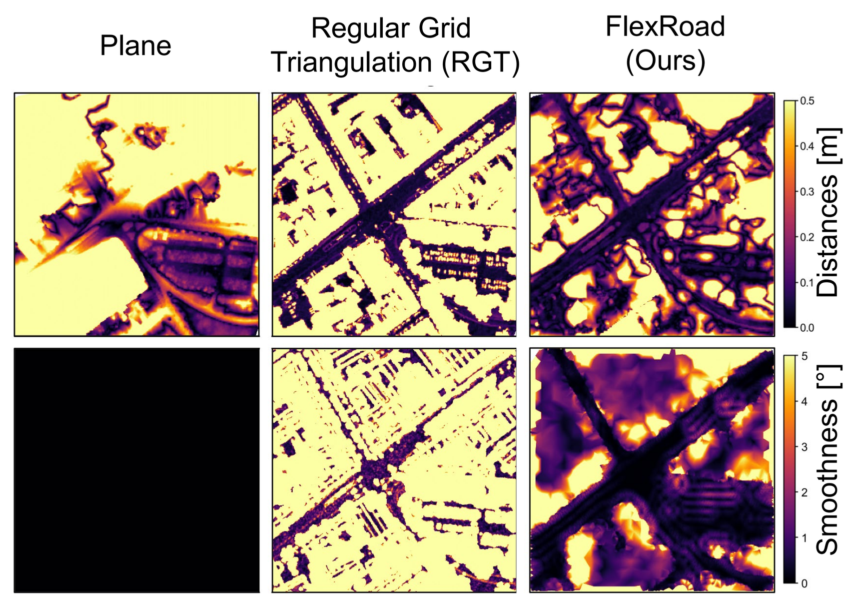
Results

Major Achievements

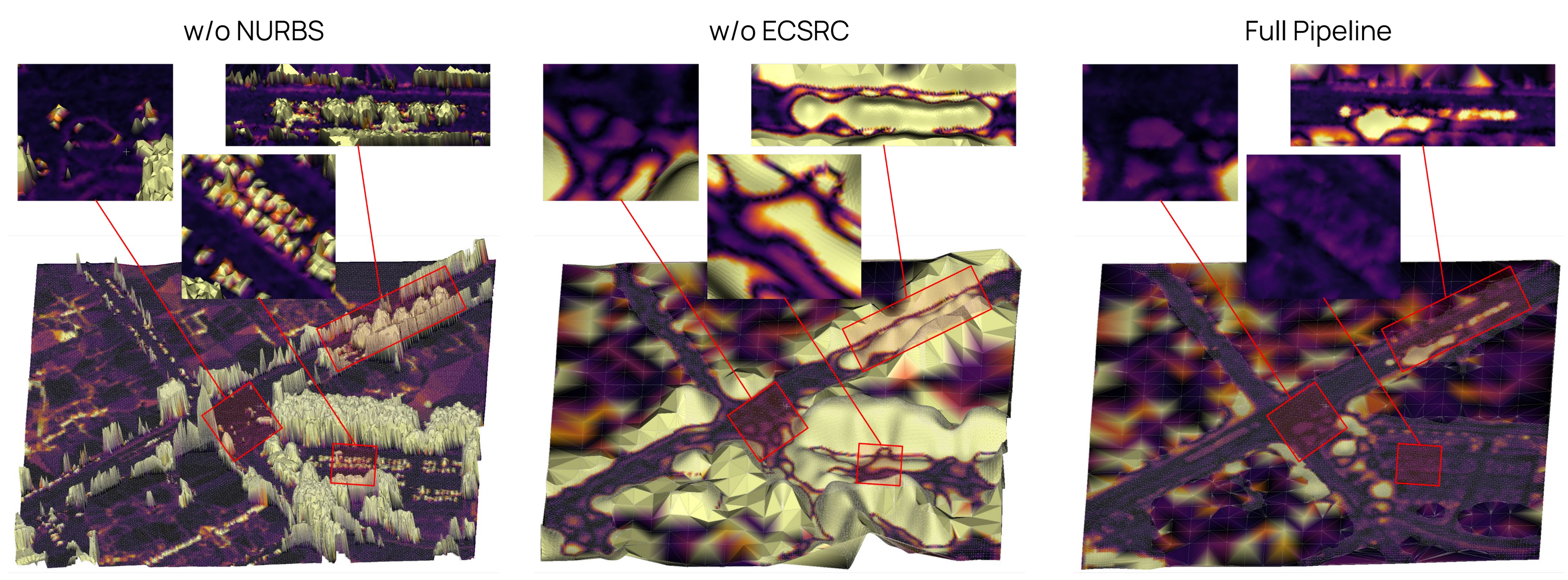
- **76% improvement** in road accuracy vs. planar fitting.
- **93% reduction** in surface roughness vs. raw reconstruction.
- **73% fewer triangles** by dynamic sampling.
- **Validated** on both GeoRoad and photogrammetry-based DSC3D [1] datasets.

	Method	$\mathcal{L}_2$ (m) ↓ Road	$\mathcal{L}_2$ (m) ↓ Terrain	MAD (°) ↓ Road	MAD (°) ↓ Terrain	T ↓
GeRoD	Plane	2.05	2.343	**0**	**0**	**2**
	RGT	**0.415**	1.773	15.55	22.191	124K
	FlexRoad (Ours)	0.483	**0.332**	1.01	3.019	33K
DSC3D	Plane	1.163	2.727	**0**	**0**	**2**
	RGT	0.195	15.411	7.185	15.78	45K
	FlexRoad (Ours)	**0.106**	**0.524**	0.43	1.927	40K

Quantitative Results on GeRoD and DSC3D [1].



Qualitative Results: L2 distances and smoothness.



Ablation: L2 error visualization.

Conclusion

- FlexRoad is the **first** NURBS-based refinement approach for **3D road surfaces**.
- Our **GeRoD benchmark** introduces a dataset for road reconstruction evaluation.
- FlexRoad **outperforms existing methods**, balancing accuracy, smoothness, and compactness.

References

[1] O. Dhaouadi, J. Meier, L. Wahl, J. Kaiser, L. Scalerandi, N. Wan delburg, Z. Zhuo, N. Berinpanathan, H. Banzhaf, and D. Cremers, "Highly accurate and diverse traffic data: The deepscenario open 3d dataset," in 2025 IEEE Intelligent Vehicles Symposium. IEEE, 2025.

[2] B. Delaunay, "Sur la sphère vide," Bulletin de l'Acadéemie des Sciences de l'URSS. Classe des sciences mathématiques et na, vol. 1934, no. 6, pp. 793–800, 1934.

[3] L. Piegl and W. Tiller, The NURBS book. Springer Science & Business Media, 2012.