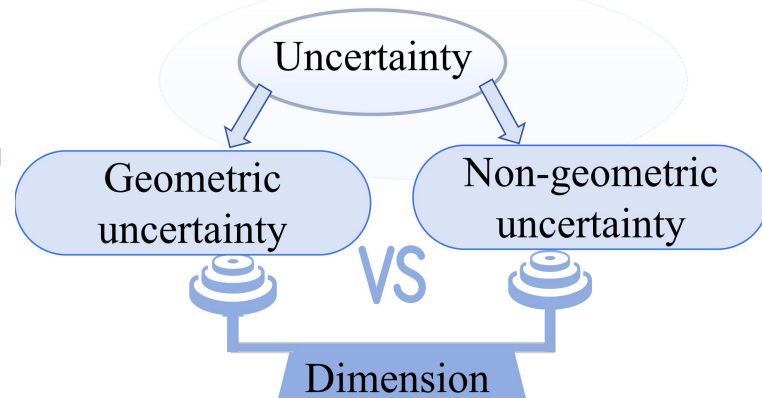
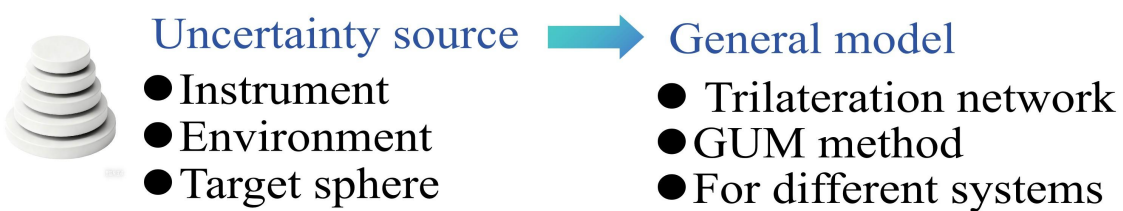
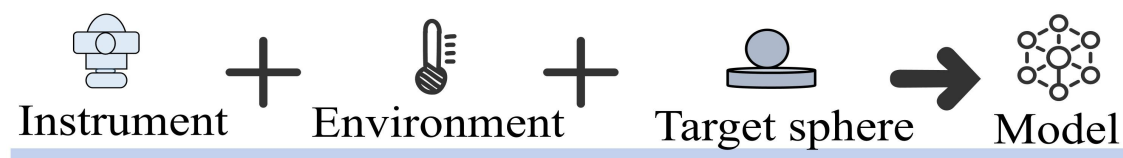


1. Abstract

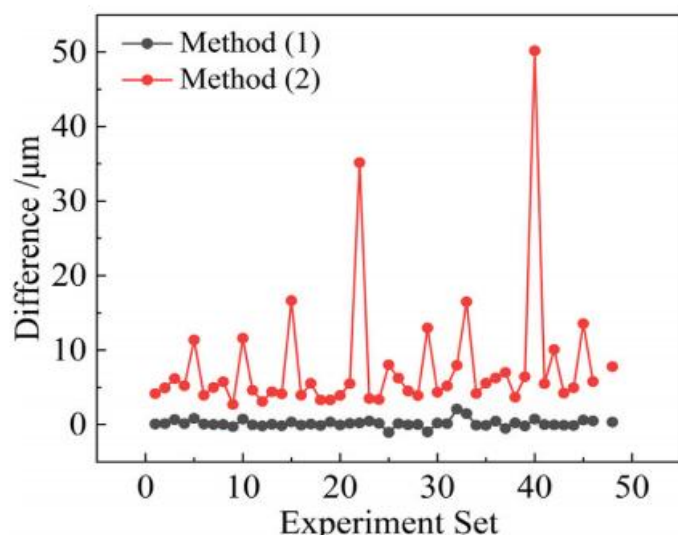
Under high-noise and multi-disturbance environments, high-precision consistency in large-scale engineering measurement remains challenging. This study establishes a GUM-based uncertainty propagation model for multi-station laser tracking, proposes control point optimization based on 3D Delaunay networks and barycentric coordinate invariance, and develops point cloud registration residual modeling with linear deformation inversion and compensation, forming a systematic framework from uncertainty modeling to deformation compensation.

2. Method I: Uncertainty Modeling & Optimization Priority

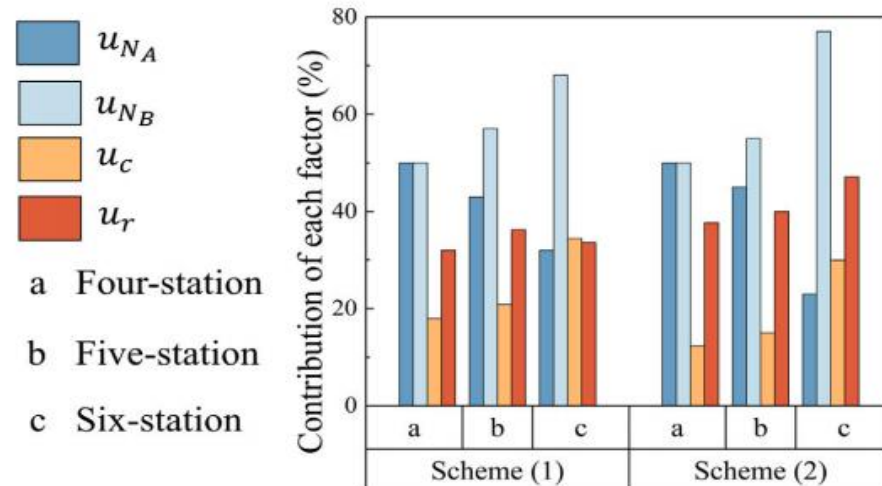
Goal: Assess multi-laser multilateration and decide whether to optimize geometric or non-geometric factors.



Finding ①: Higher accuracy uncertainty



Finding ②: Optimization priority changes



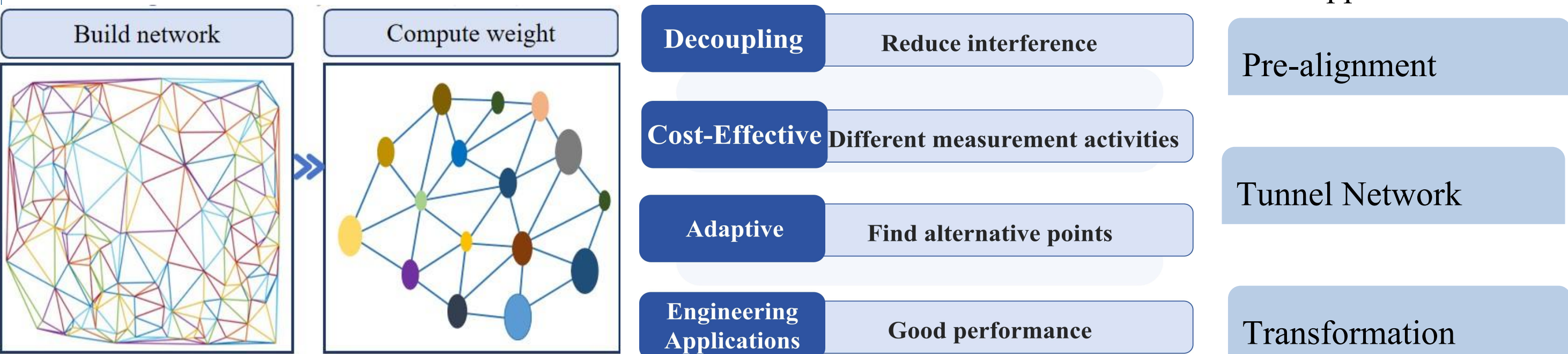
3. Method II: Common-Point Layout Optimization

Goal: Build cost-effective and adaptive control point network robust to station, error, and scale disturbances.

① Process

② Pros

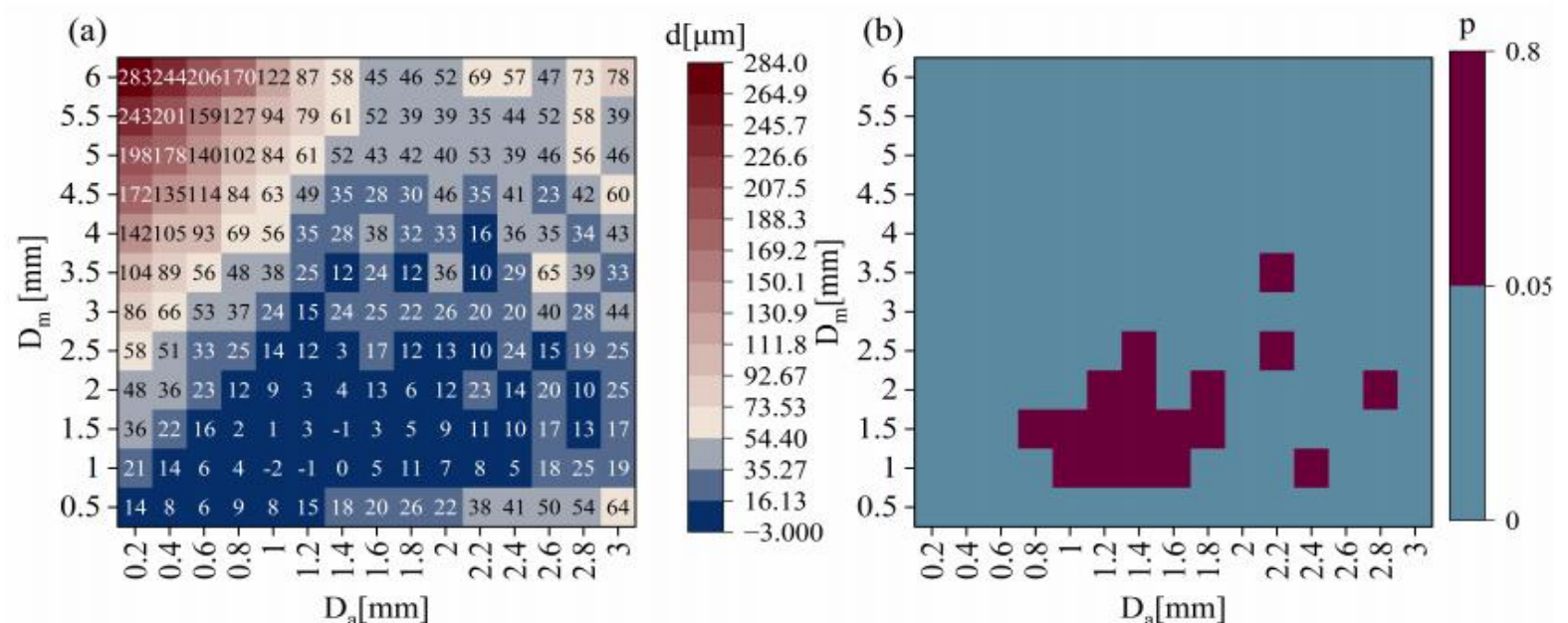
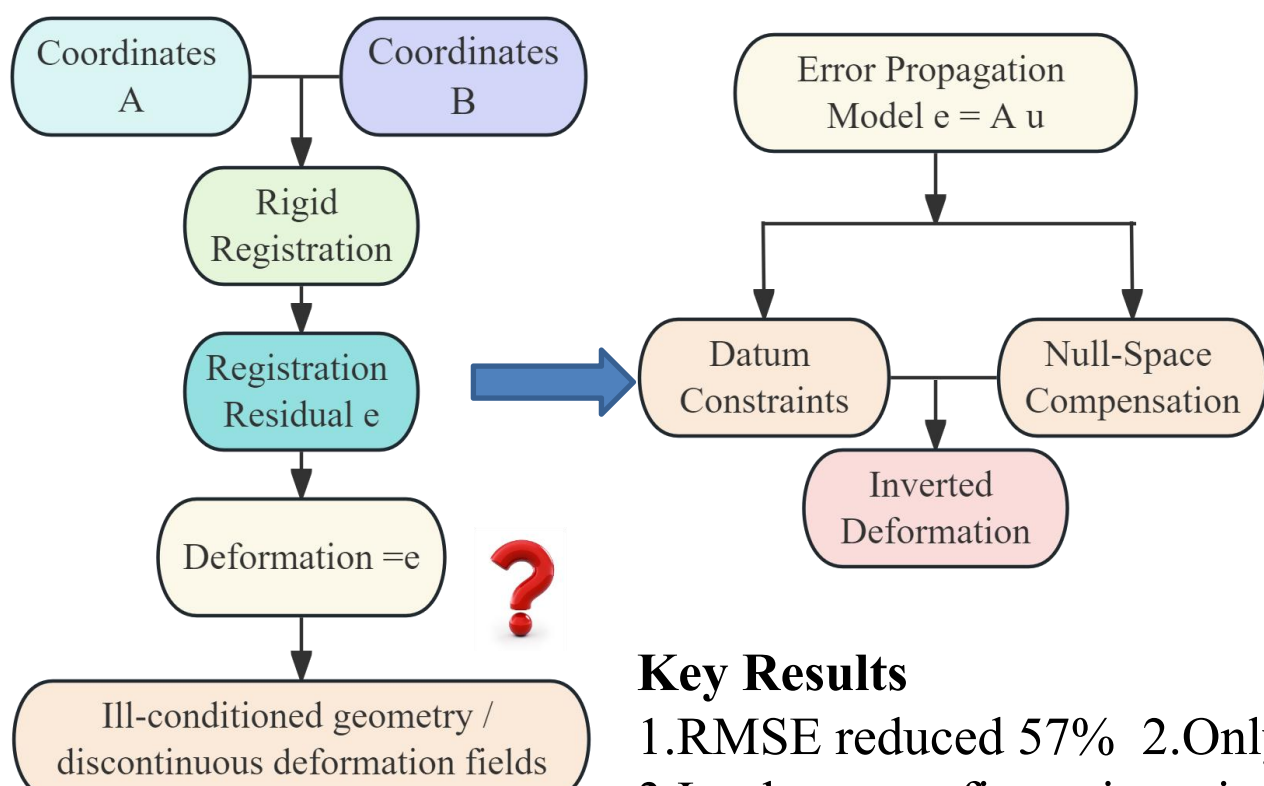
③ Application



This method achieves 31% fewer nodes while maintaining 9.8 μm accuracy.

4. Method III: Deformation Inversion

Goal: Decouple registration and deformation for unbiased estimation.



(a) RMSE difference d ; warmer = larger advantage.

(b) p -value; dark red = significant ($p < 0.05$).

Key Results

1. RMSE reduced 57%
2. Only 8–10 reference points are needed to outperform the conventional method.
3. In planar configurations, it outperforms even under small deformations