Unmanned Aerial Vehicle (UAV) Path Planning for Automated Bridge Inspection and 3D Reconstruction

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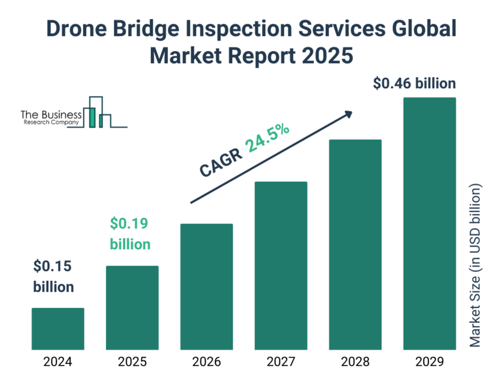
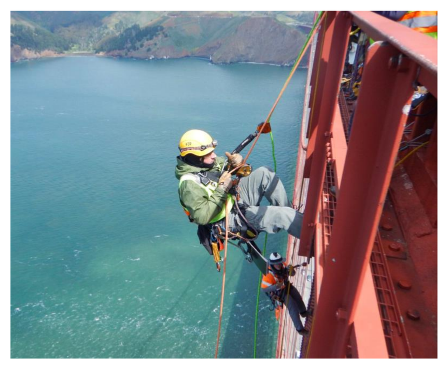
Motivation: Enhancing automated UAV-based bridge inspection and reconstruction

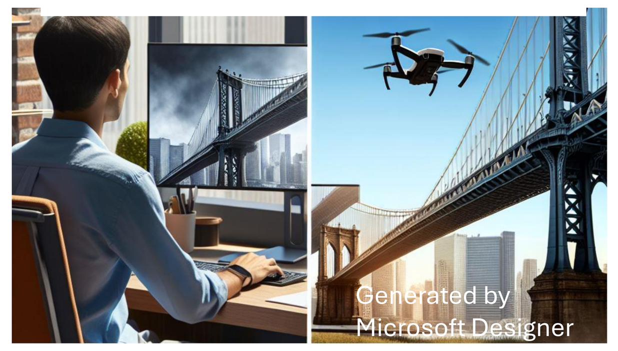
There are more than 617,000 bridges across the US. Currently, 42% of all bridges are at least 50 years old, and 7.5% are considered structurally deficient. The NBIS require safety inspections at least once every 24 months for highway bridges that exceed 20 feet in total length located on public roads.




Manual inspection

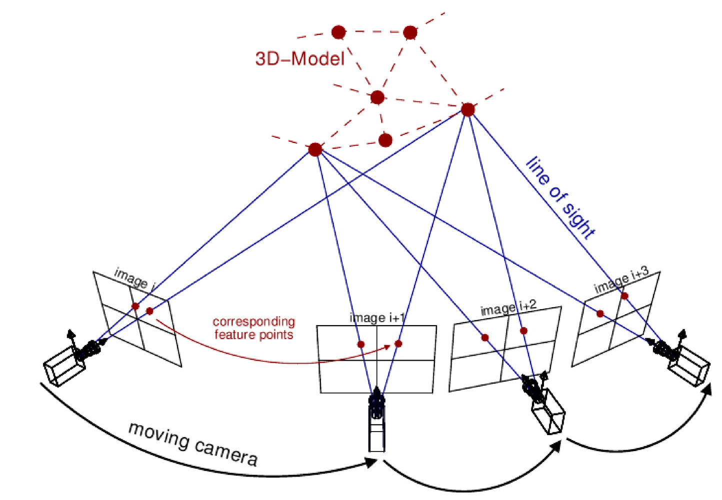

UAV inspection with manual control

Path planning necessary here!



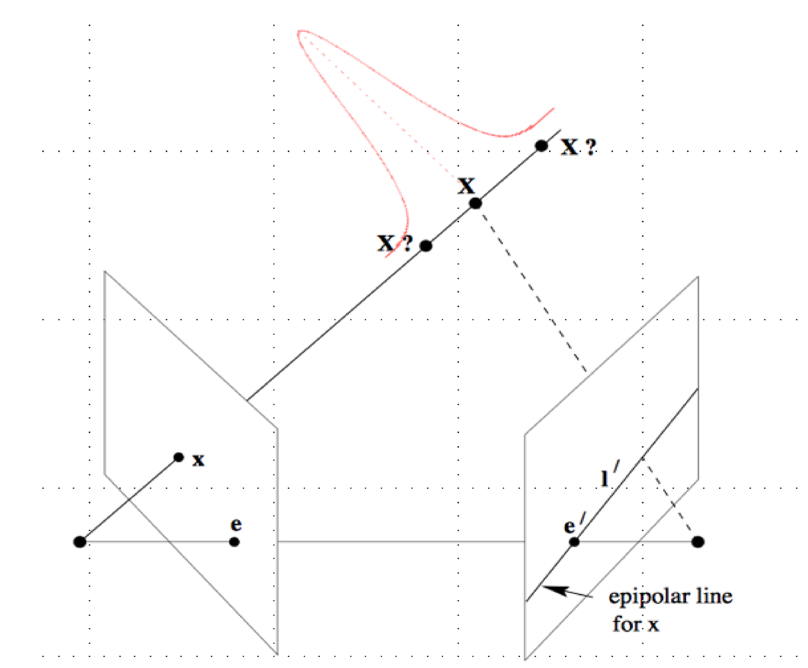
Fully automated inspection

Method: Path planning for 3D reconstruction



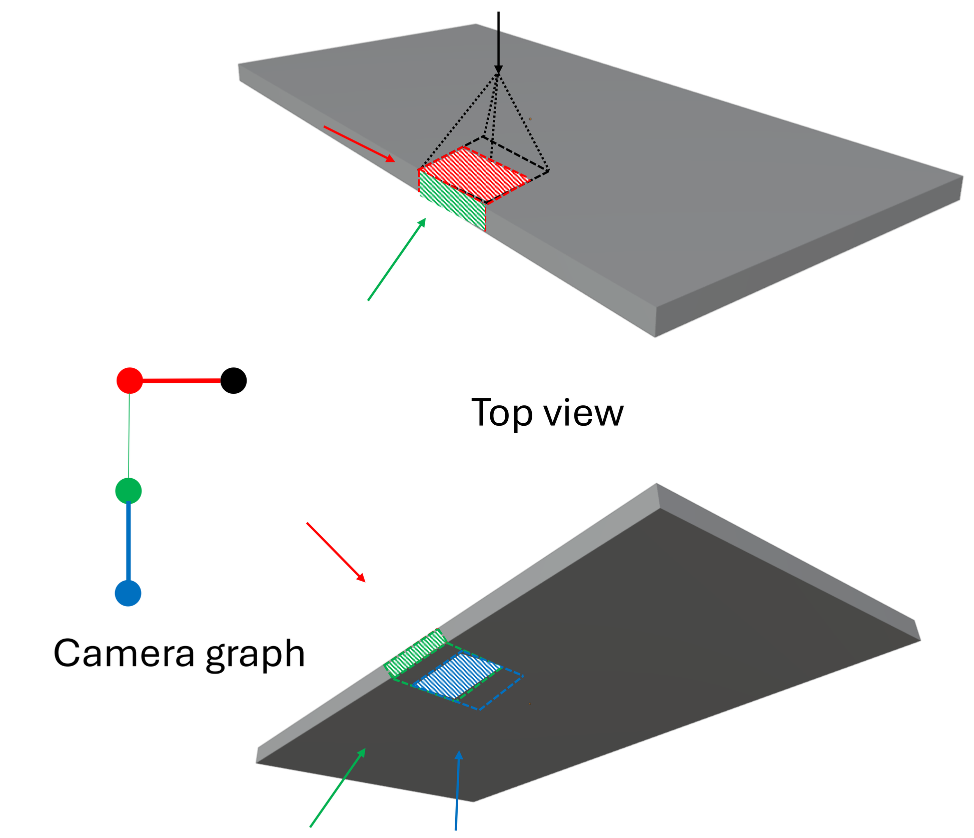
Structure from Motion principle:
- Feature detection
- Camera registration
- Triangulation
- Bundle Adjustments

Can be optimized through path planning



Parallax angle ↑
Distance ↓ ➡ Uncertainty ↓
Number of cameras ↑

Evaluation on triangulation quality



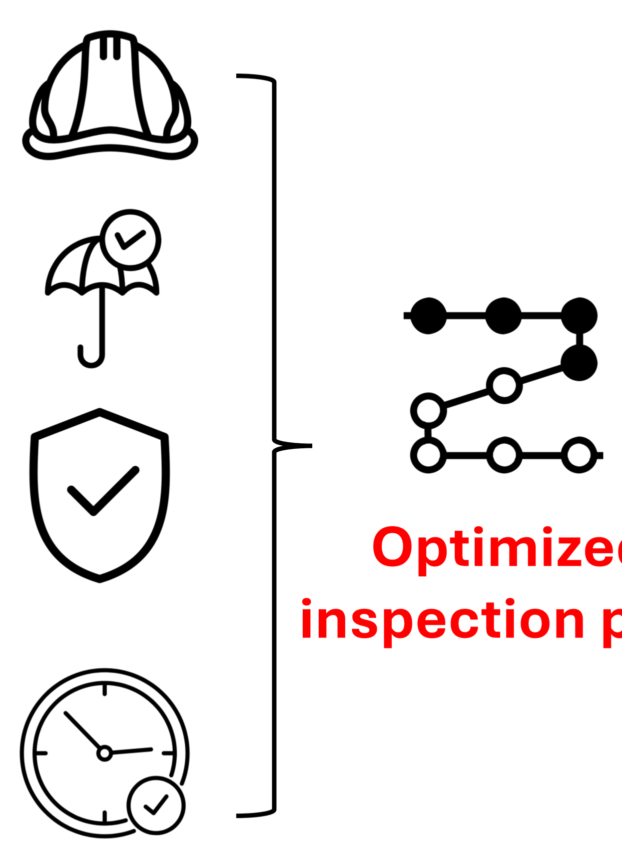
Evaluation camera registration

Method: Path planning for rapid visual inspection

Optimization constraints:
- **Safety**: Keep a safety distance with structure and obstacle
- **Coverage**: Guarantee on coverage to ensure the comprehensiveness of inspection
- **Visual quality**: A distance and inclination requirement must be met for a face to be considered visible

Optimization objective:
- **Path length**
- **Number of camera poses**

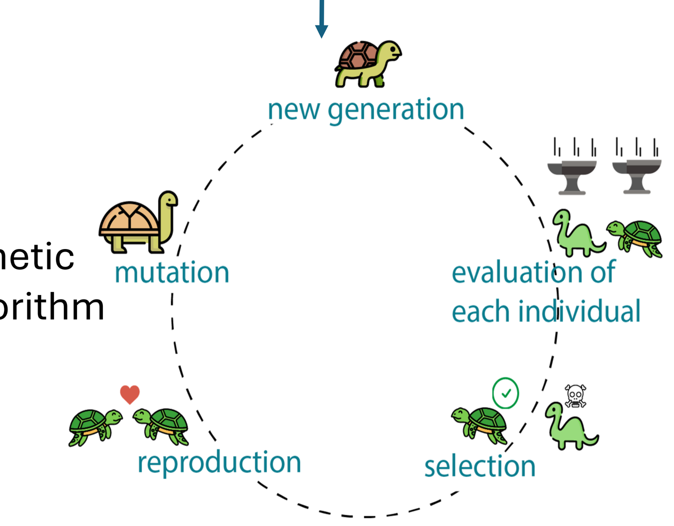
Inspection efficiency



Optimized inspection path

First step: Viewpoint Positions optimization $P=\{(x_i, y_i, z_i \mid i=0,\ldots,n)$

Omnidirectional camera assumption



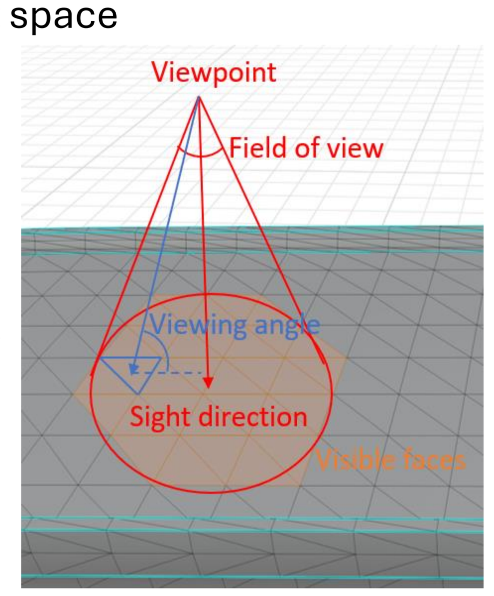
P^*
Optimal path positions

Second step: greedy sight selection

$P^* \times (\theta, \phi)$ Sight space

Greedy selection

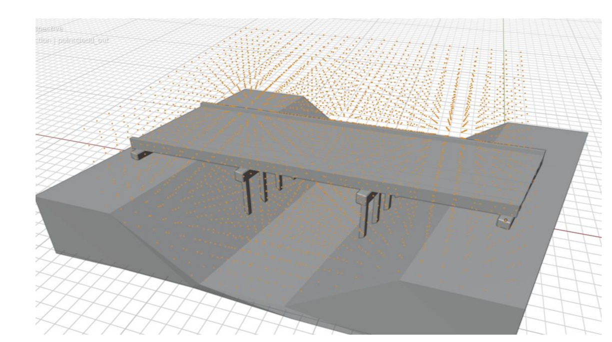
Visibility evaluation

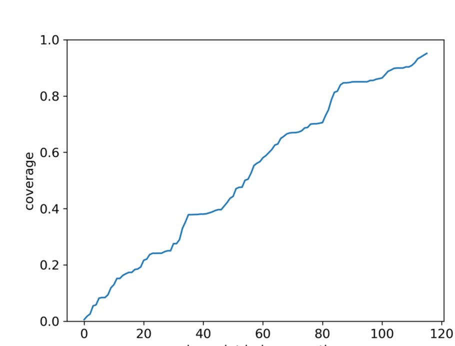


$C^*=\{c_i=(x_i, y_i, z_i, \theta_i, \phi_i) \mid i=0,\ldots,m\}$
Optimal camera poses

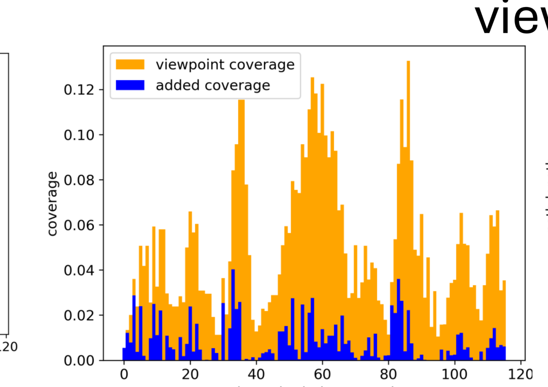
Experiment results: visual inspection


Photo of target bridge

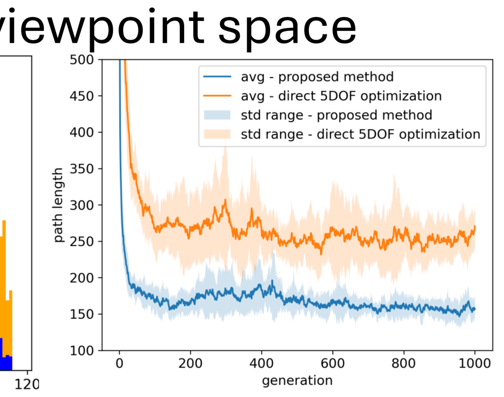

Geometric model and viewpoint space



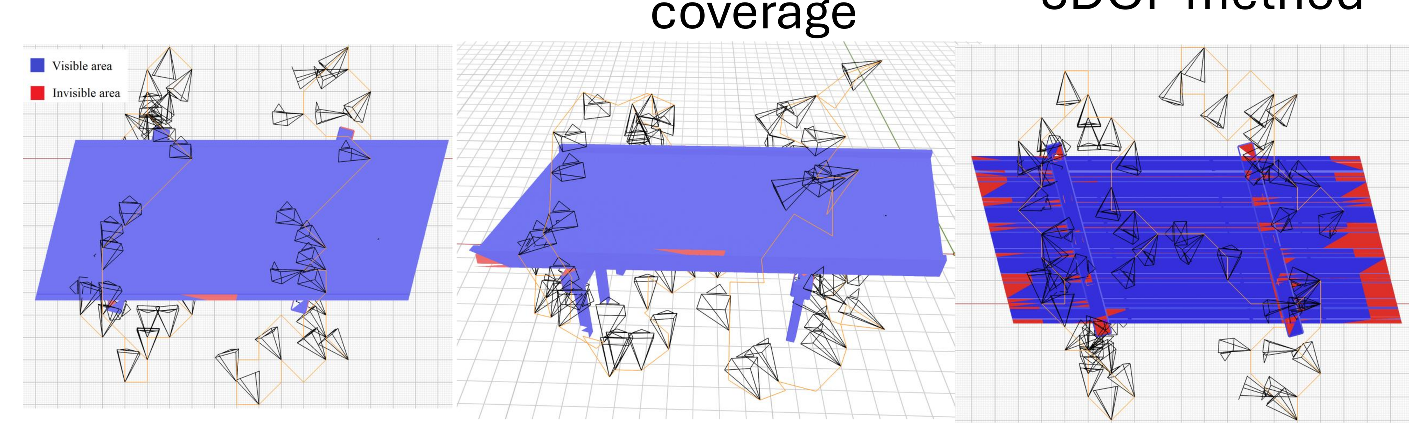
Accumulated coverage



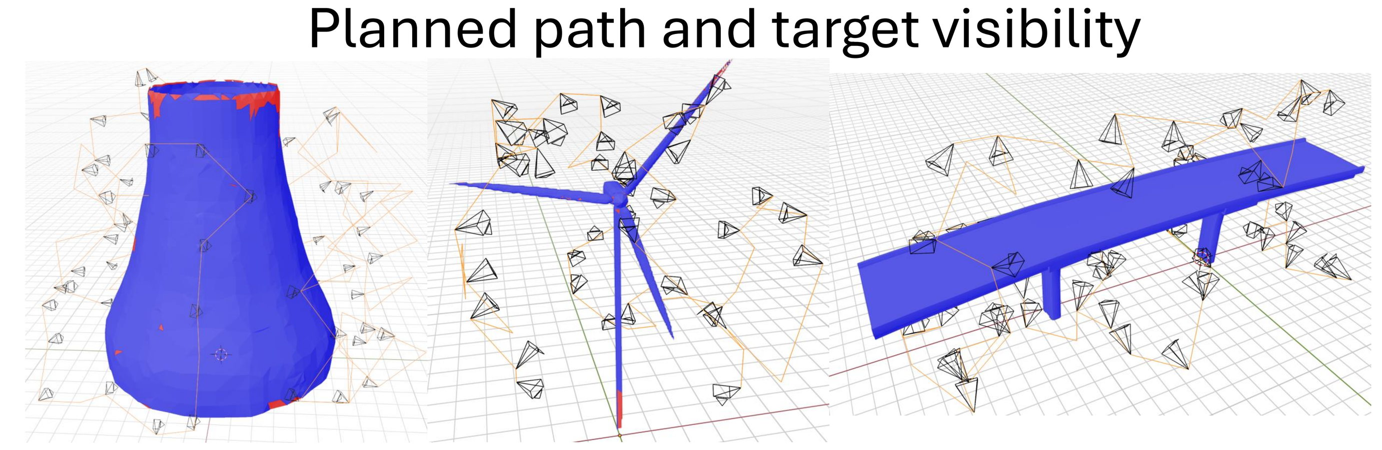
Single viewpoint coverage



Comparison with 5DOF method

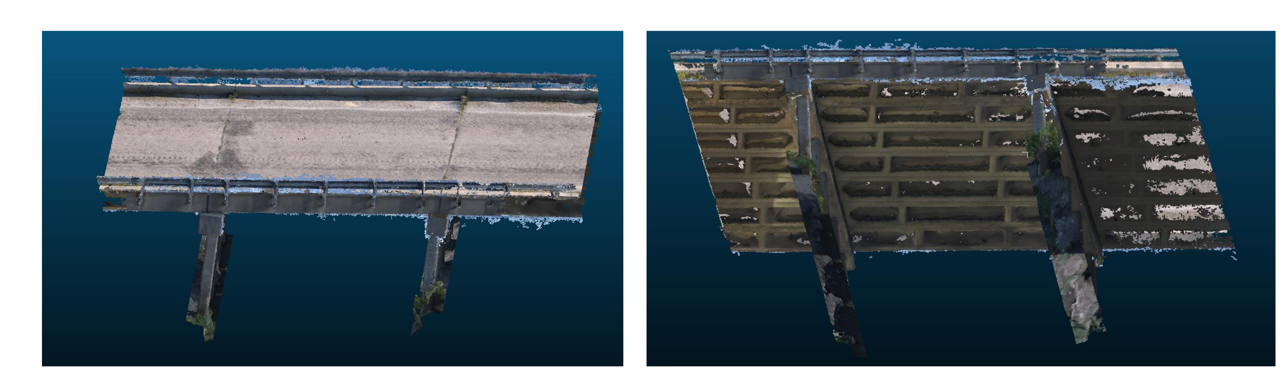


Planned path and target visibility


Experiment on other assets

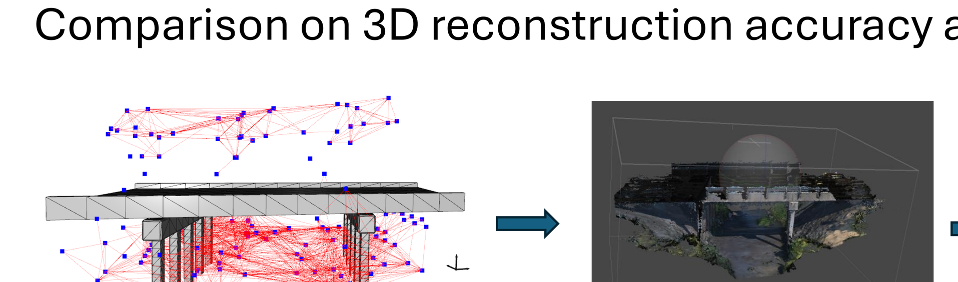
Experiment results: 3D reconstruction

3D reconstruction results of Metashape


3D reconstruction results considering quality metric in optimization

Experiment no.	Experiment setting	Mean Accuracy error (m)	Mean Completeness error (m)	Length (m)	No. of cameras
1	Rapid visual inspection	0.025	0.164	137.6	93
3	Metashape (a commercial software	0.020	0.082	768.0	213
4	Optimization considering triangulation quality metric	0.022	0.012	209.6	214

Comparison on 3D reconstruction accuracy and completeness



Facing problem: camera graph is sometimes not fully connected

Consequence: the faces covered by the cameras disconnected to the camera graph can't be aligned

Ongoing work: consider camera graph connectivity as optimization objective