ISPRS Workshop on Geo-Information for Disaster Management (Gi4DM 2022)

3D SCENE RECONSTRUCTION AND PATH PLANNING METHOD FOR UAV IN GNSS-DENIED ENVIRONMENT

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INTRODUCTION

1.1 BACKGROUND

GNSS

√ open and spacious environment

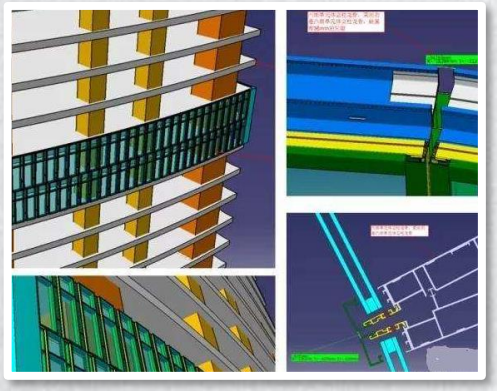
× ground surface covered

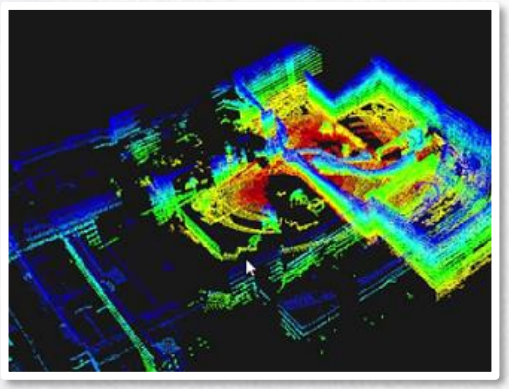
complex **dangerous** **unpredictable**

Unmanned robots

- discovery
- localization
- surveying
- mapping

3D Scene Reconstruction

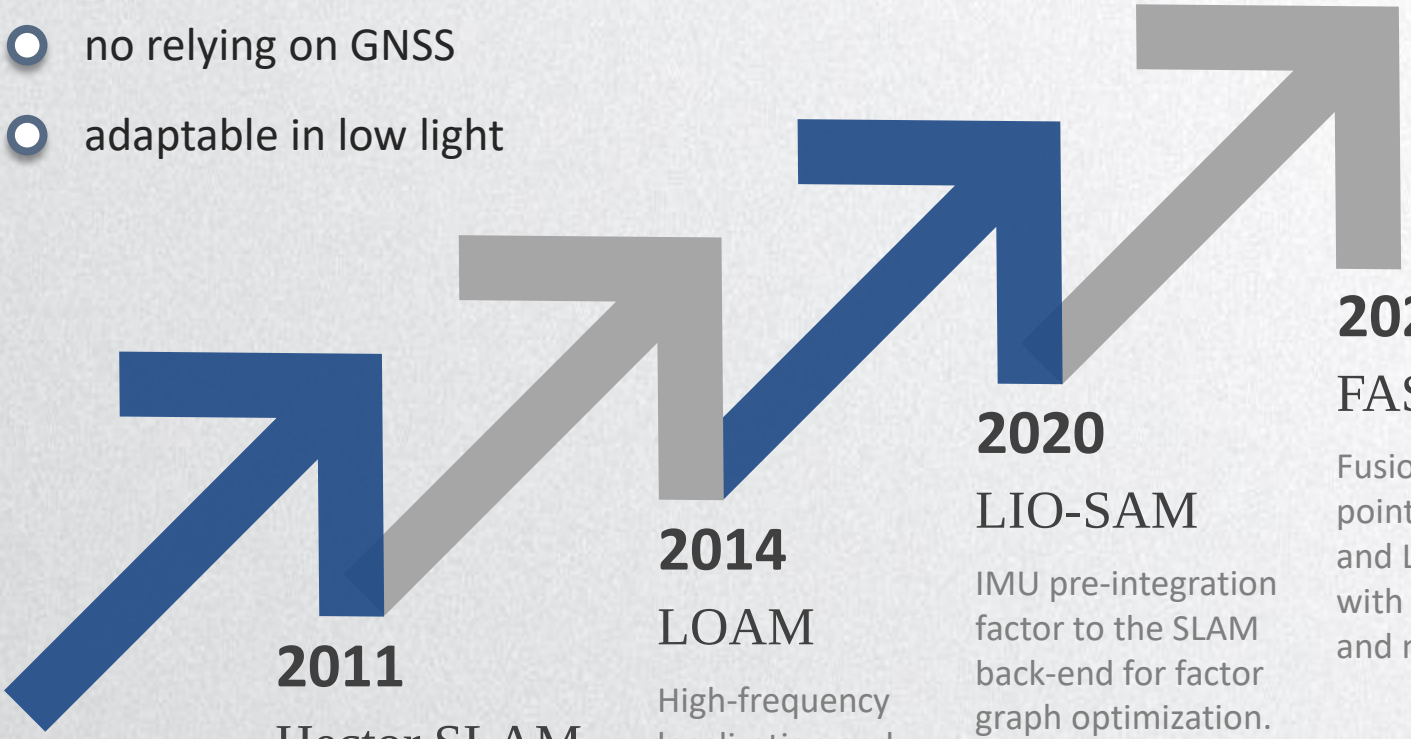




BIM / Terrain models	Optical images	LiDAR
Damaged, incorrect representation.	Lighting condition required.	Robust, rapid, and effective.

Laser SLAM

- autonomous localization
- no relying on GNSS
- adaptable in low light



2011
Hector SLAM
Point cloud matching by aligning point clouds to grid maps.

2014
LOAM
High-frequency localization and low-frequency mapping.

2020
LIO-SAM
IMU pre-integration factor to the SLAM back-end for factor graph optimization.

2021
FAST-LIO
Fusion of feature point data of IMU and LiDAR, dealing with fast motion and noises.

1.2 RELATED WORK

Path Planning

- basis for navigation
- graph-based algorithm
- robust and efficient

Our method

- 3D scene reconstruction by laser SLAM → Effective solution for disaster surveying
- Improved PRM path planning → Better computational efficiency
- GNSS-denied UAV autonomous flight → Useful support in relief and rescue

2

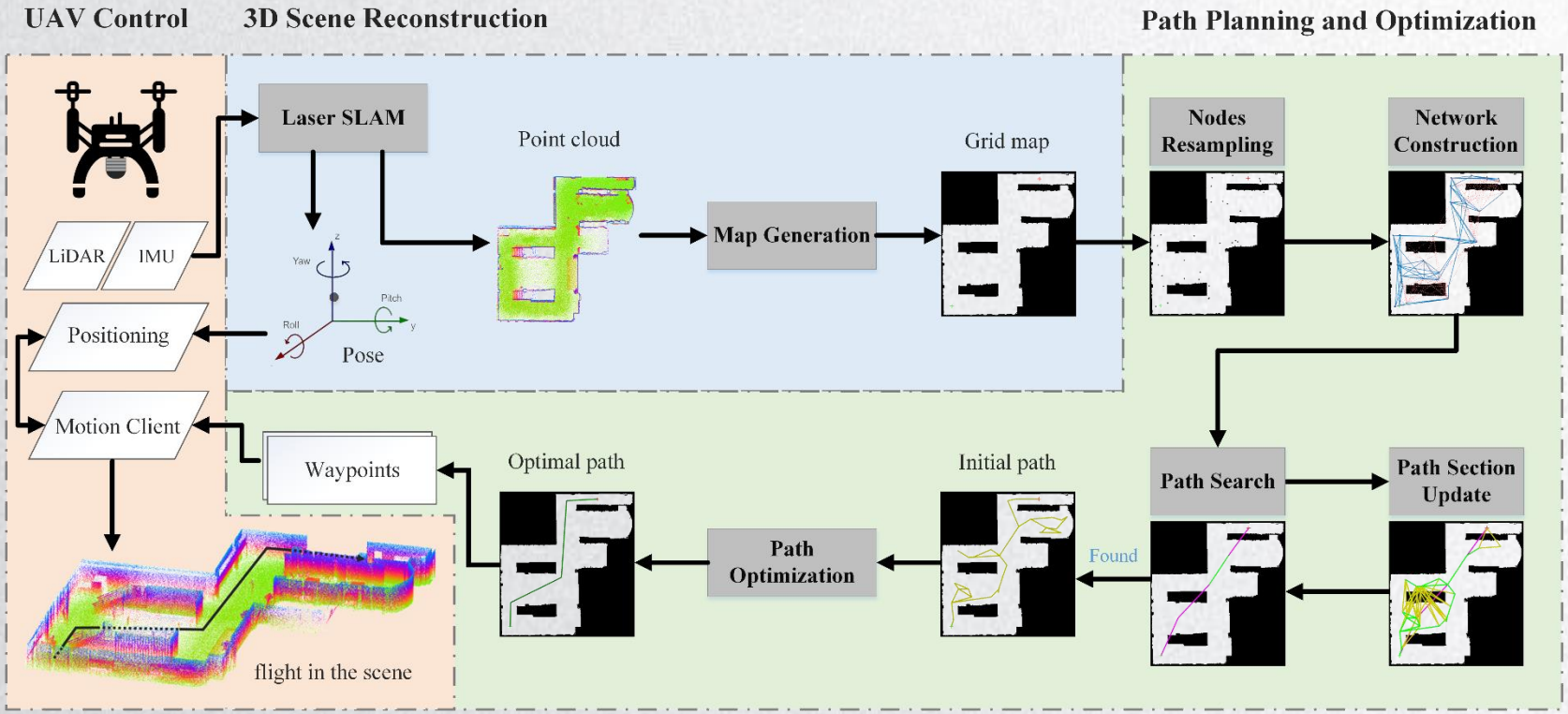
METHODOLOGY

2 SYSTEM STRUCTURE

1 3D Scene Reconstruction

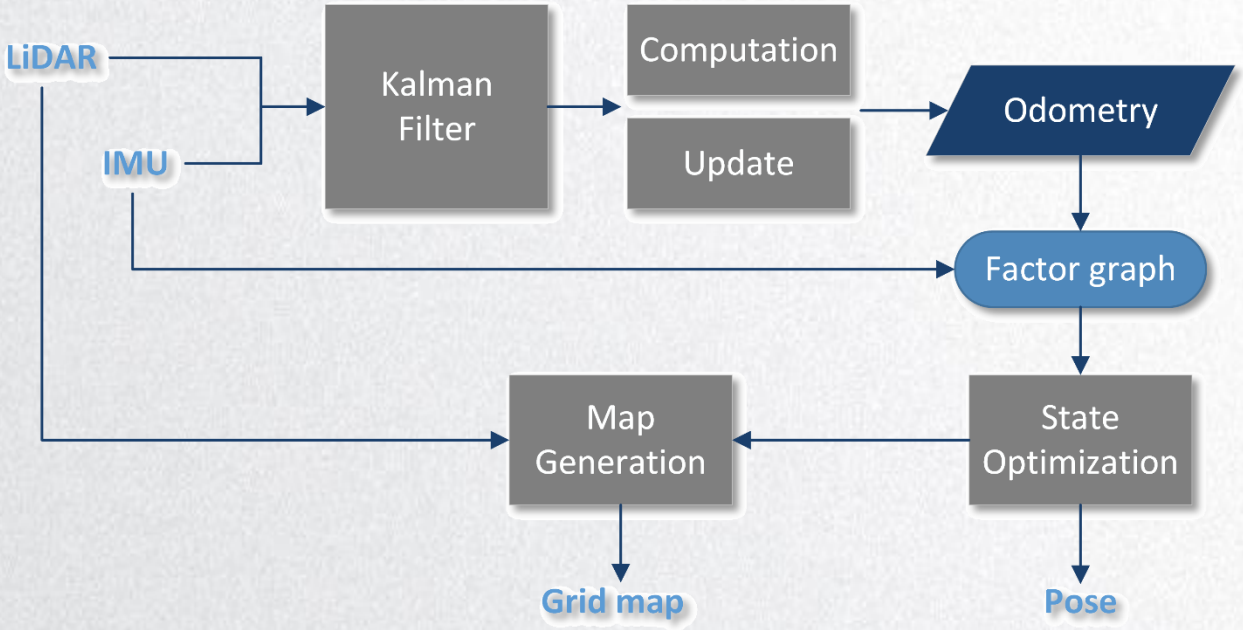
2 Path Planning and Optimization

3 UAV Control



2.1 LASER SLAM 3D SCENE RECONSTRUCTION

- **Input**
  - LiDAR
  - IMU
- **Front-end**
  - Kalman filter
- **Back-end**
  - factor graph



- **Output**
  - pose ⇒ localization
  - grid map ⇒ planning

⇒ navigation

2.2 CONNECTION NETWORK INITIALIZATION

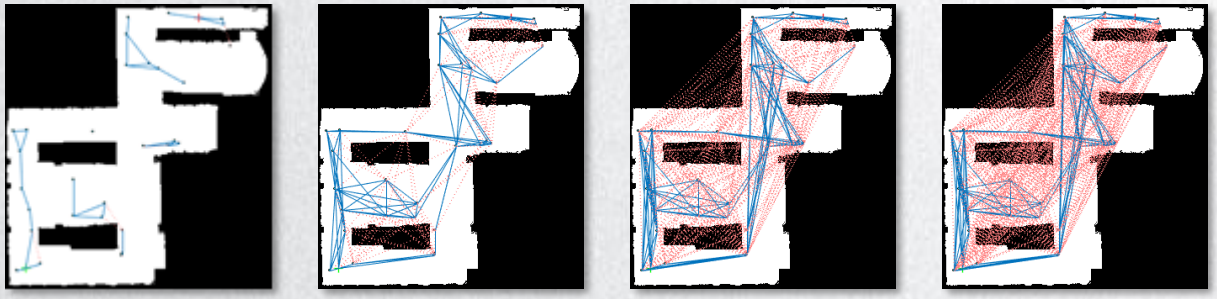
Initialization Process

Initialization → Sampling → Connection → Network

Setting connection distance: to increase computational efficiency by **reducing ineffective connectivity checks**. Besides, The threshold should be adapted to the number of sampling nodes.

good edges
(visible, collision-free)

bad edges
(invisible, collided)

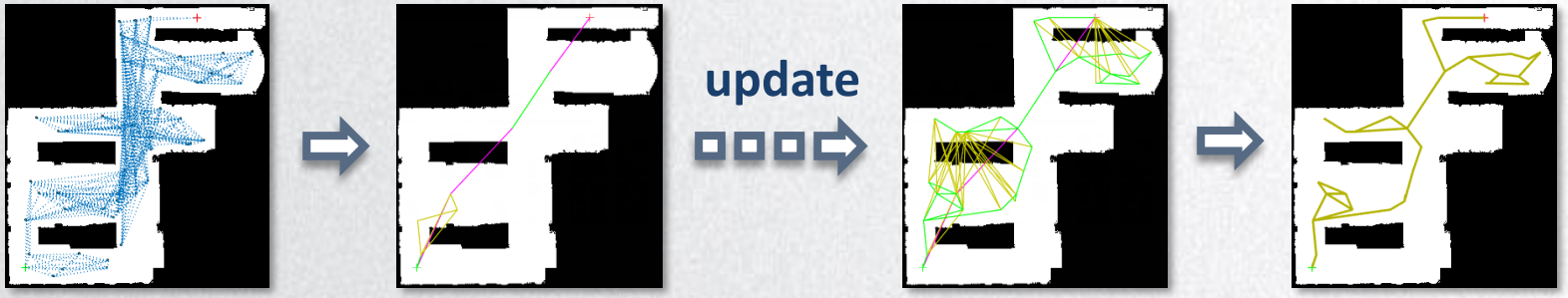


connection dis. = 0.1 0.25 0.5 1

2.2 PRM PATH PLANNING & OPTIMIZATION

Path Search and Incremental Update

Greedy search strategy: perform connectivity checks **only when necessary**, resulting in great reduction of collision checks.



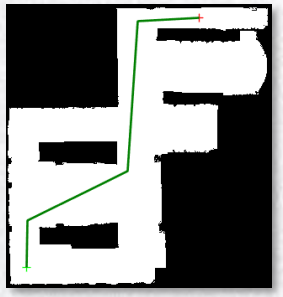
initial network | initial search | final search | candidate path

reorder

Waypoint Reordering

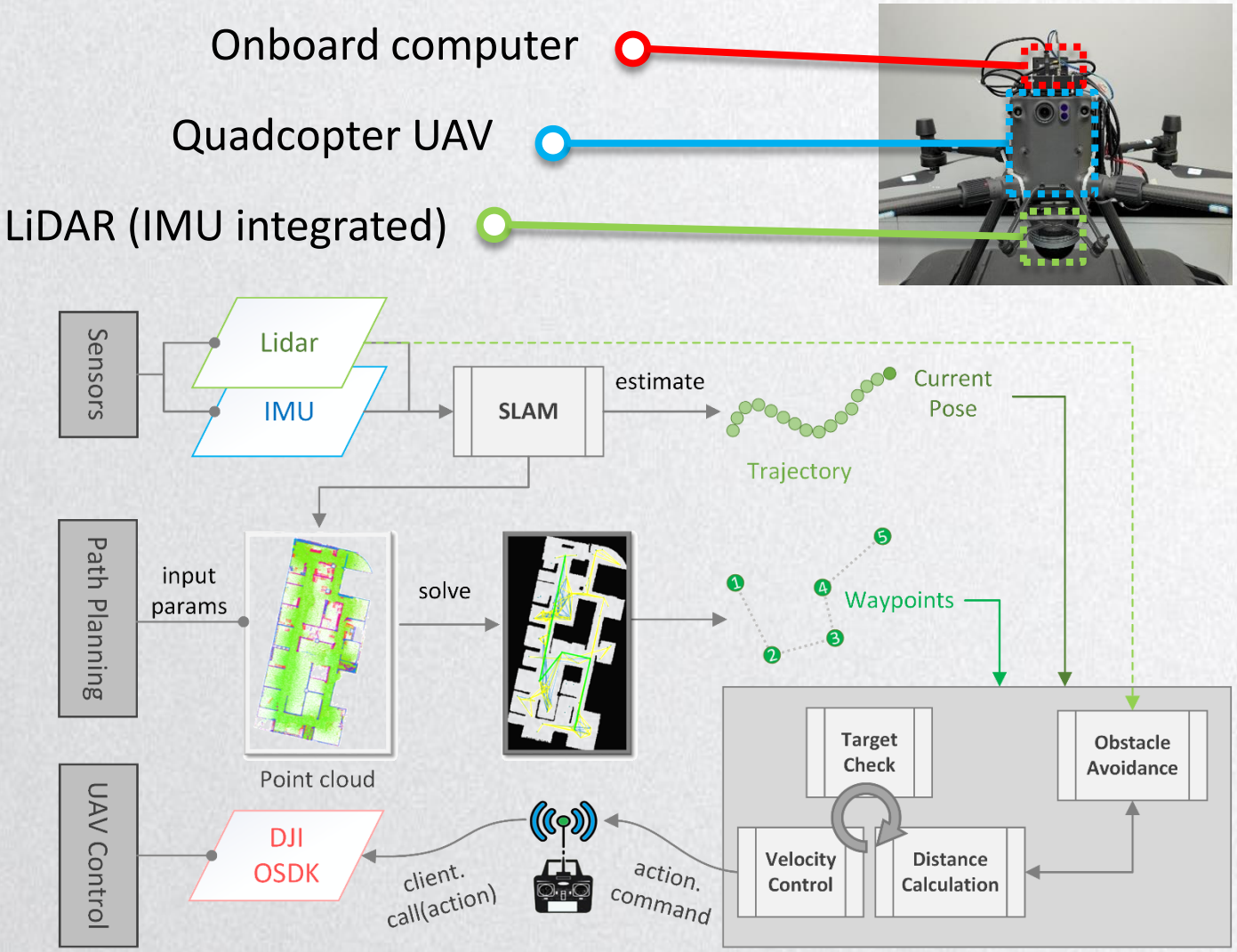
Cross-waypoint connectivity check: Connect two **distant and non-adjacent** waypoints which are visible to each other, and discard the other waypoints in between.

- straightforward
- extendable to path smoothing



optimal path

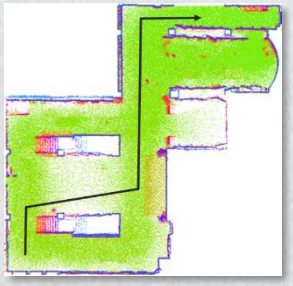
2.3 GNSS-DENIED UAV POSITIONING AND NAVIGATION

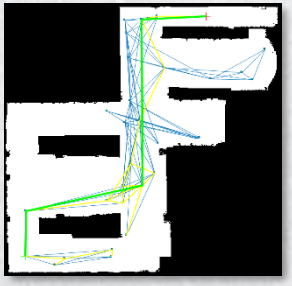


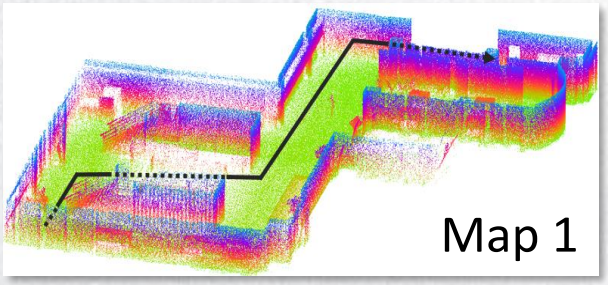
3

EXPERIMENTS

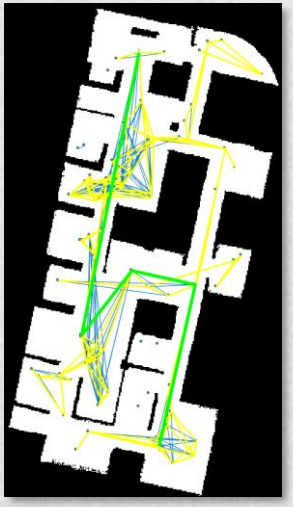
3.1 EXPERIMENTAL CASES

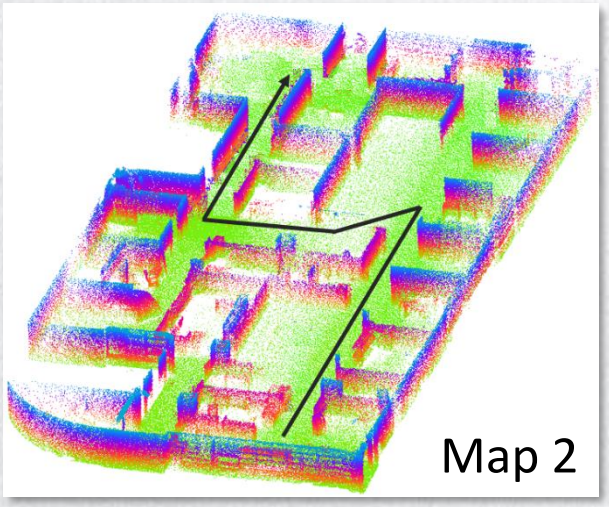




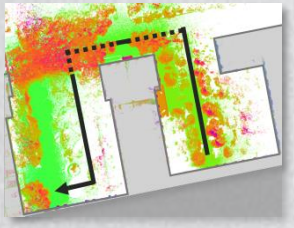


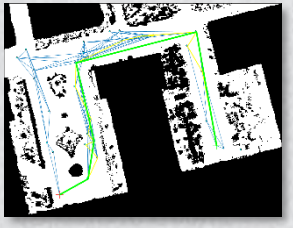
indoor,
low complexity,
big obstacles

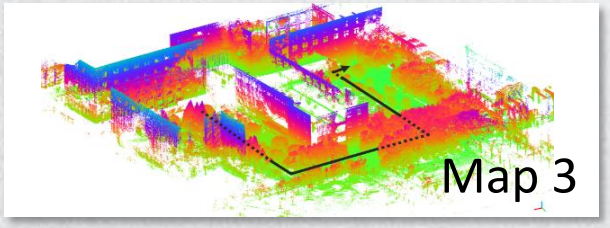




indoor,
high complexity,
several rooms







outdoor,
lots of noise

3.2 EXPERIMENTAL RESULTS

Evaluation Metrics: Planning time | Path Length

Planning Time

Most time consuming: network initialization (basic PRM), path update and search (ours).

- Basic PRM -

Node num. : ↗

Connectivity check : ↷

Redundant : ↗ (ineffective edge check)

Time : ↑ (rapid)

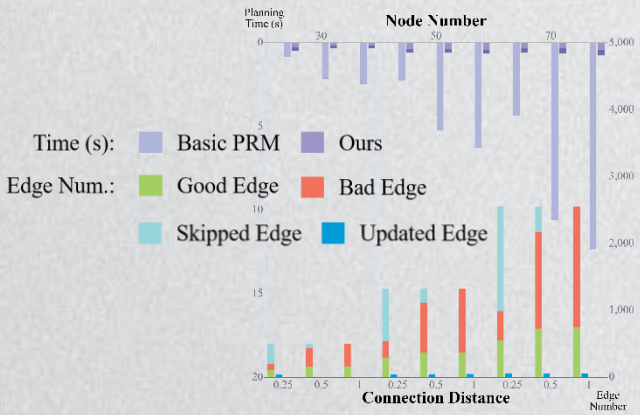
- Ours -

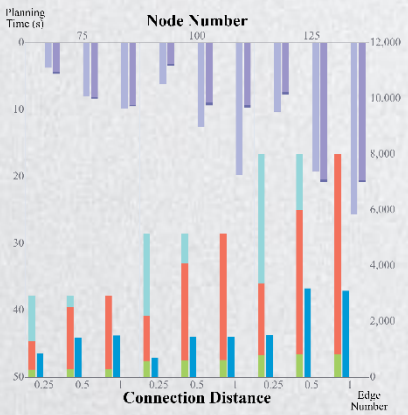
Node num. : ↗

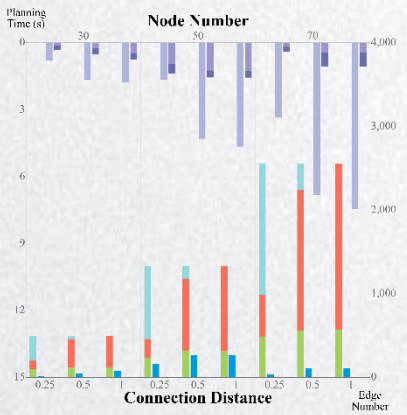
Connectivity check : — (in need)

Redundant : ↗ (candidate length)

Time : ↗ (steady)







3.2 EXPERIMENTAL RESULTS

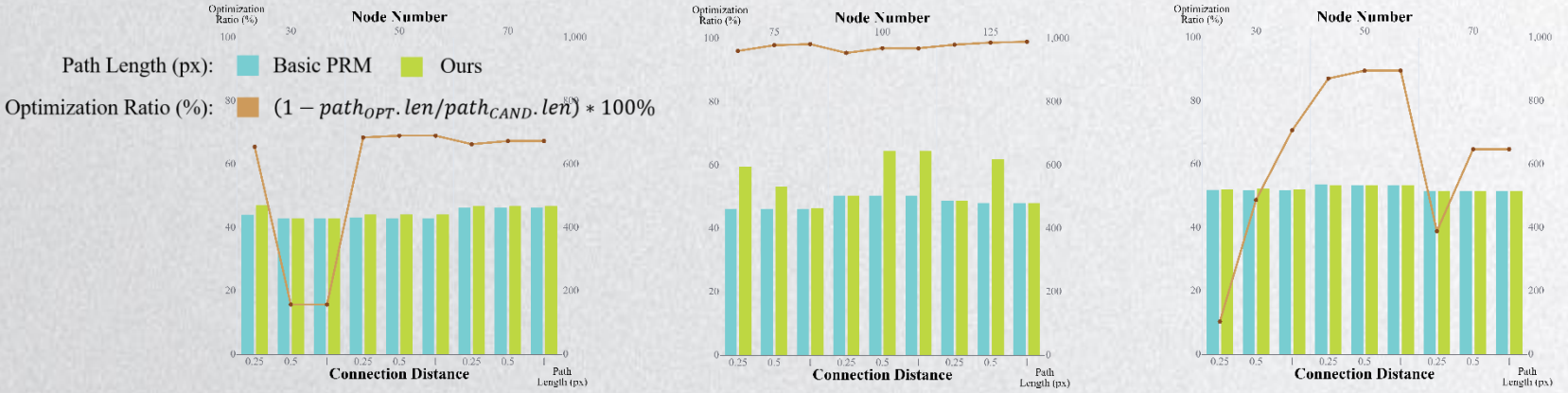
Path Length

With connection dis. increasing, the path length of our method gradually approaches that of the basic PRM. **When node num. is large**, our path optimization shows a good effect on shortening the path length.

Although our path length may be slightly larger than that of the basic PRM, which is because we use an incremental search strategy instead of a global one, it is still **well worth the sacrifice for computational efficiency**, especially in an unpredictable and dangerous situation after a disaster, where we solve a path the sooner the better.

Summary

- improvement in computational efficiency
- reasonable optimal path
- good performance in noises



4

CONCLUSION & DISCUSSION

4.1 CONCLUSION

Method of 3D scene reconstruction and path planning for UAV in GNSS-denied environment

- 3D scene construction
- computational efficiency
- optimal path

4.2 DISCUSSION

Scene Scale Limit ?

Our method is originally designed for the scale of the indoor space of buildings and their outdoor surroundings after disasters. It is possible but not recommended that we use the method in **large-scale situations**, since there exists the **localization drift problem of SLAM**, especially in open and spacious outdoor environment.

A Potential Solution

Integration of GNSS into our system. SLAM is used for **localization and modeling** in key areas, while GNSS is used for **global positioning and correction**.

Future Work

- Integration of GNSS in our system.
- More robust method, more complex scenes.
- Autonomous discovery and exploration.

5 ACKNOWLEDGEMENTS & REFERENCES

Acknowledgements

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