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Cooperative and Autonomous Mapping for Heterogeneous NAVs

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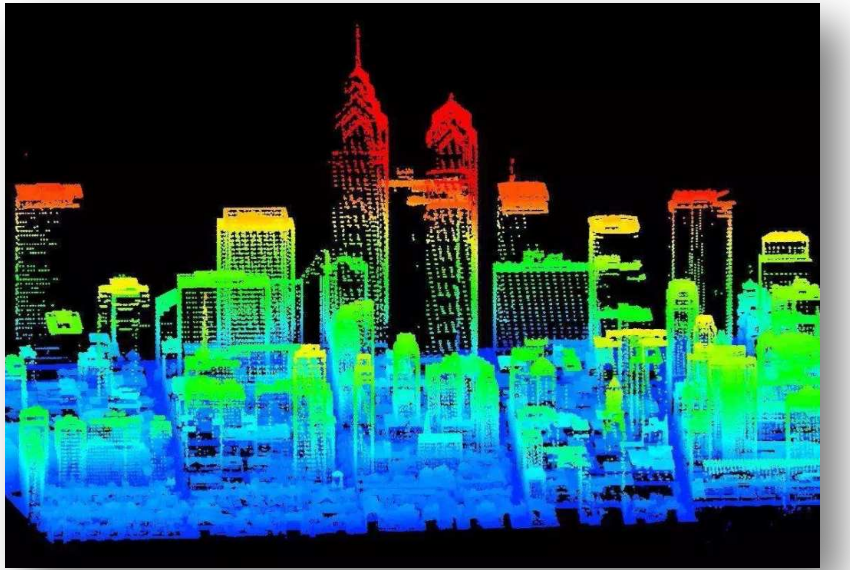
PART ONE

Introduction

Classic Mapping

Expensive equipment and human intervention



Large scenes and extensive point cloud

Autonomous Mapping for NAV

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Introduction
Autonomous Mapping for Nano-UAVs(NAVs) refers to the process of mapping without external control signal input, the NAV utilizes only the data from its own sensors to to navigate and complete the mission.

advantages

- Easy Deployment
- High Agility
- High Mobility

Advantages and Disadvantages of NAV

Advantages

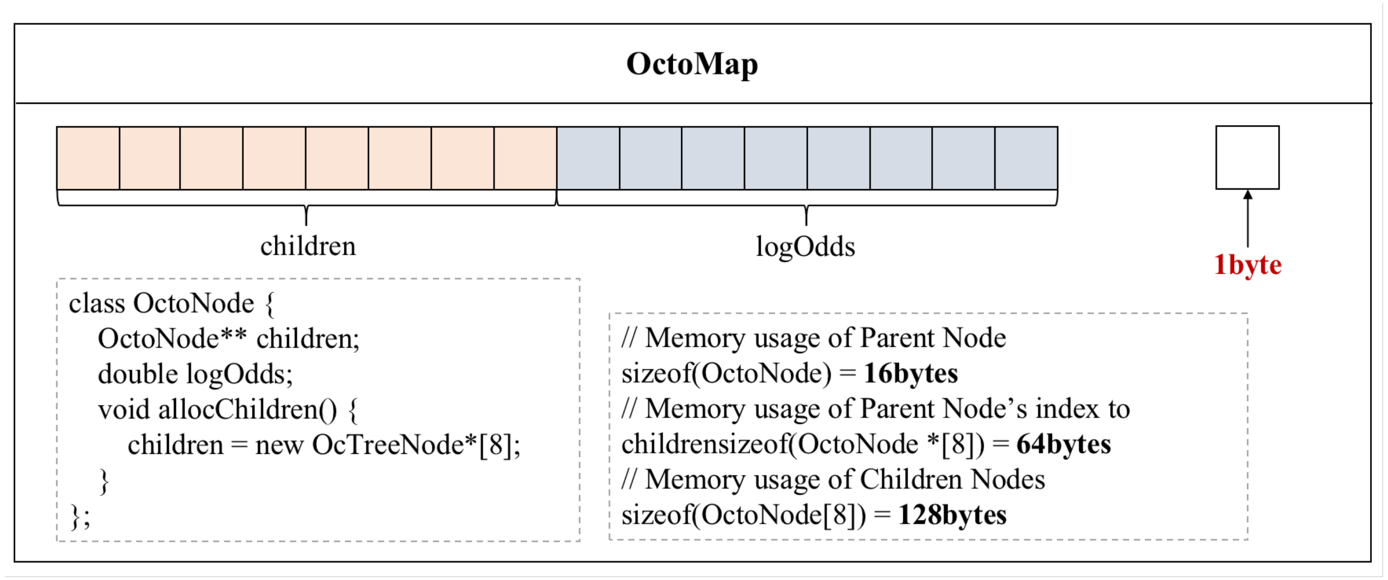
- Small size
- inexpensive
- adaptability to confined and complex environments
- Low risk of accidents

Disadvantages

- Limited sensor performance
- Low computing and storage capacity
- Limited battery life

Challenge of mapping for NAV

Challenge 1 : Lack of appropriate map model



It is too memory intensive for NAV.

Challenge of mapping for NAV

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Challenge 2 : Lack of suitable navigation strategies

Current Strategic Concerns
1、 Information Profit 2、 Exploration Efficiency 3、 …

Doesn‘t take into account **memory pressure** and **map model features** such as octree pruning operations.

Challenge of mapping for NAV

Challenge 3 : Lack of a cooperative framework for heterogeneous NAVs

Multi-NAVs collaboration

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PART TWO

TINYOCTOMAP

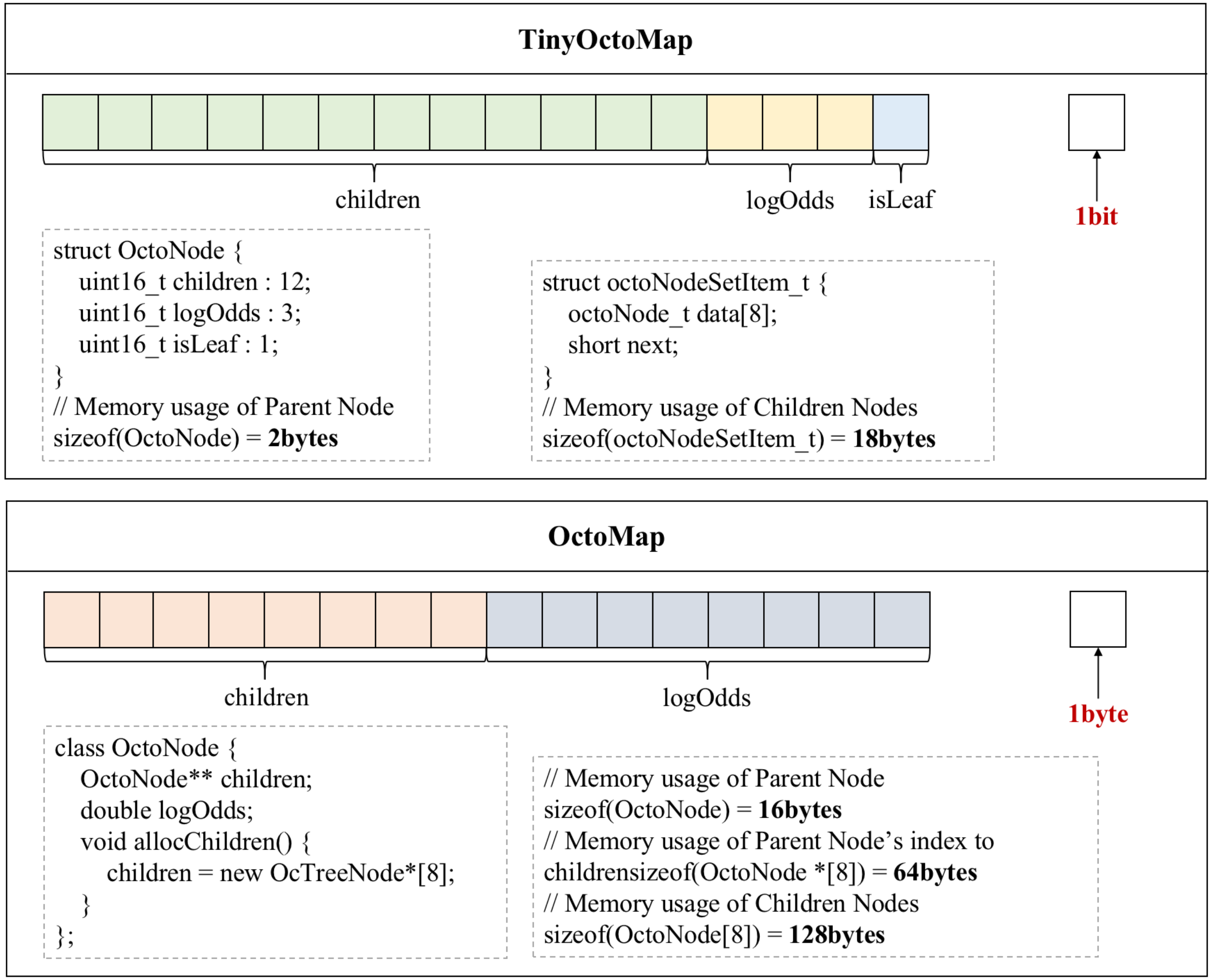
TinyOctoMap

TinyOctoMap is proposed in order to achieve efficient resource utilization in indoor NAVs navigation scenarios.

The design of the tree nodes is optimized as follows:

- **Subnode index children**
- **Node occupation level logOdds**
- **Use a bitfield to store members**

In comparison to the conventional OctoMap map model, the proposed model exhibits a significant reduction of **85.94%** in memory usage while maintaining the same number of voxel blocks.



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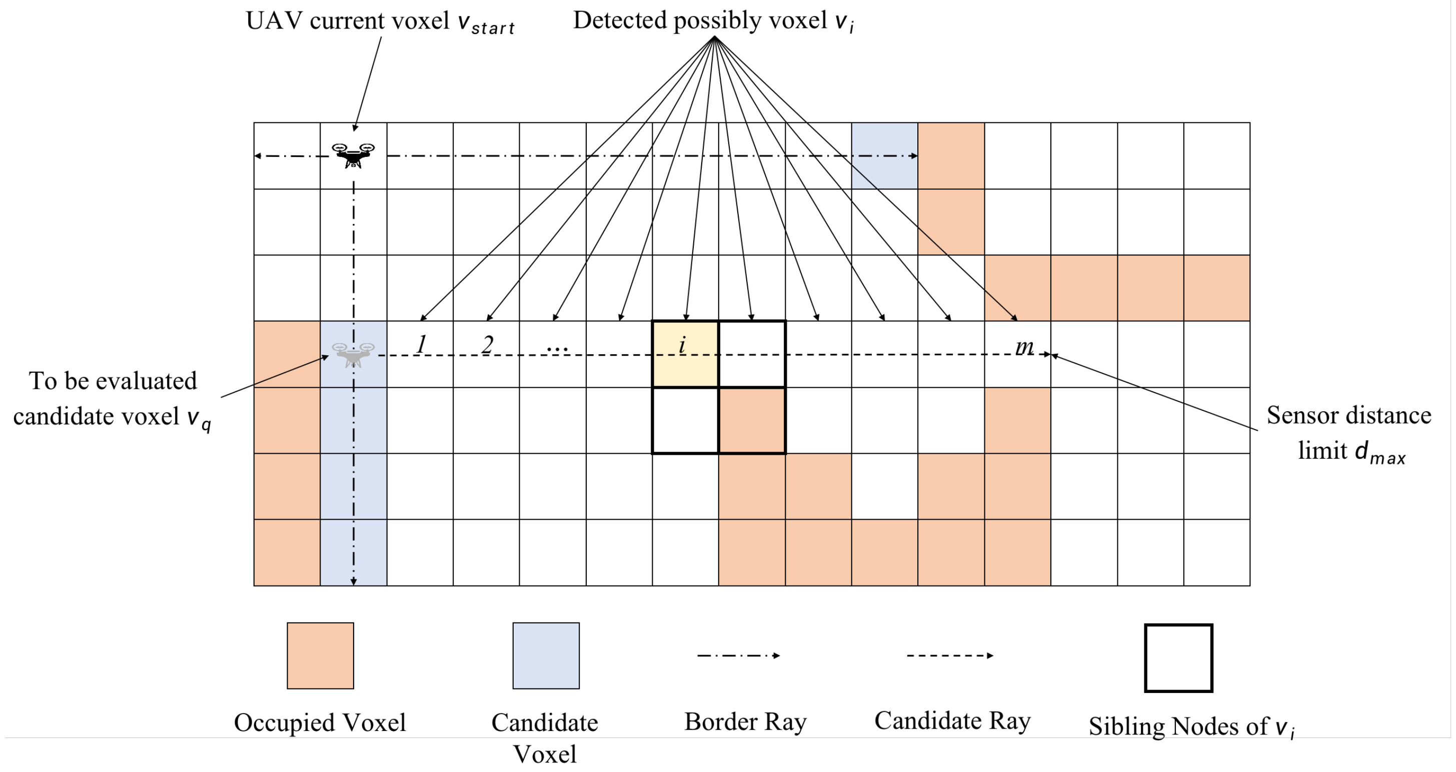
PART THREE

AUTONOMOUS EXPLORATION ALGORITHM

Design of Active Exploration

Based on Next Best View (NBV) theory

1. Selected a candidate set of next waypoints, Q, from the current location.
2. An evaluation function is established to evaluate the candidate waypoints based on the map coverage, navigation cost, state uncertainty, and other metrics.
3. The optimal waypoint for the next moment at the current position is selected based on the greedy strategy



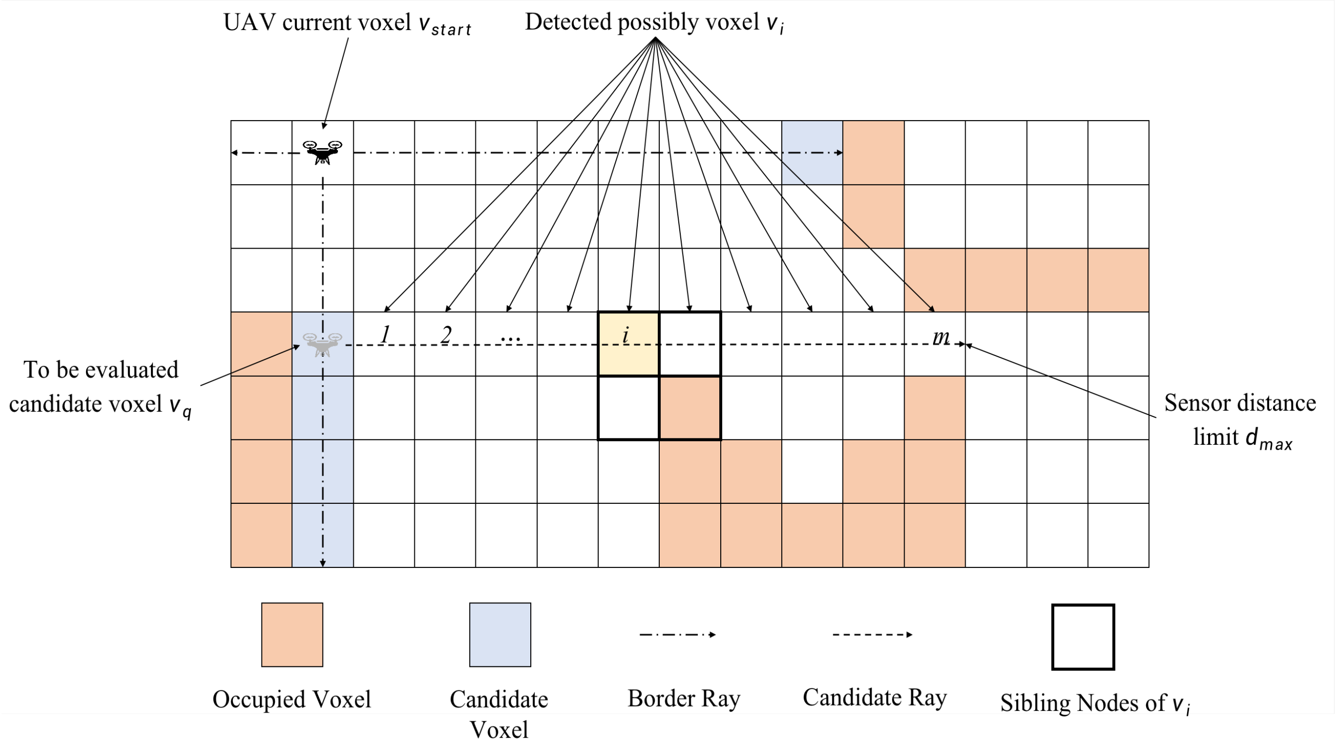
Design of Active Exploration

Single Direction Total Profit of the candidate waypoints q :

$$\widetilde{W}_{sum}(q,L) = (1-\beta) * W_{info}(q,L) + \beta * W_{prune}(q,L), q \in Q$$

The Final Decision Function:

$$\arg\max_{q\in Q} \sum_L \widetilde{W}_{sum}(q,L).$$



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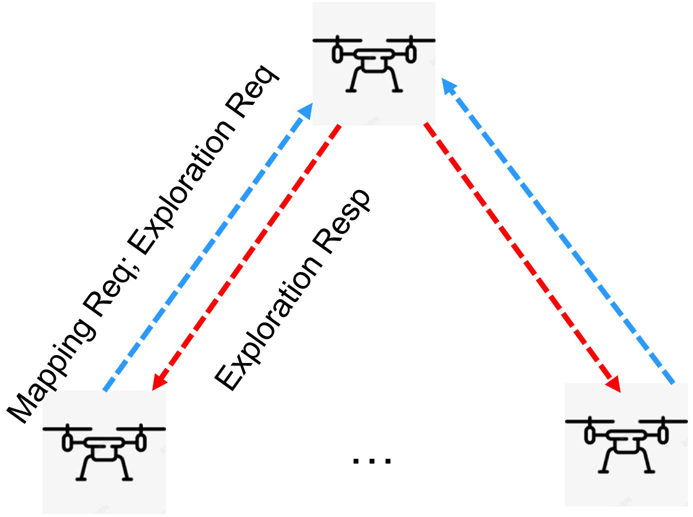
PART FOUR

EDGE-ASSISTED OFFLOADING

SYSTEM OVERVIEW

Edge-NAV:

Multi Lidar-NAVs:

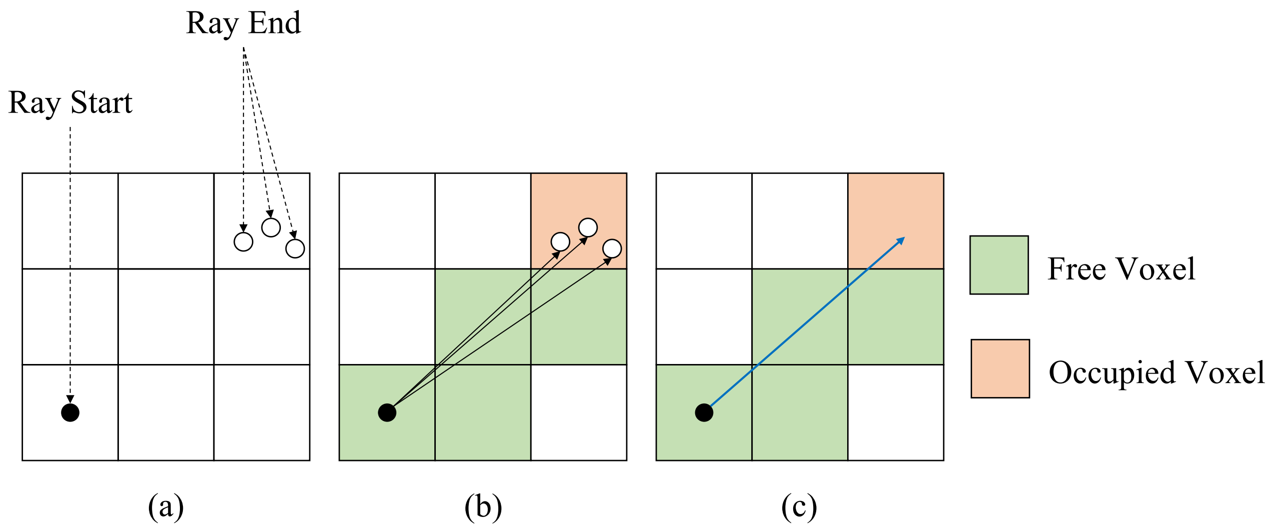


Three kinds of packets for the cooperative autonomous mapping in the heterogeneous NAV:

Message Type	Data Content
Mapping Request	Variable-length structure array
Exploration Request	current coordinate, attitude, and range
Exploration Response	next coordinate

SYSTEM OPTIMIZATION

1. Merge duplicate rays to accelerate building map



2. Adjust edge-NAV positions dynamically using the artificial potential field (APF) method

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PART FIVE

Implementation

Parameters of NAV

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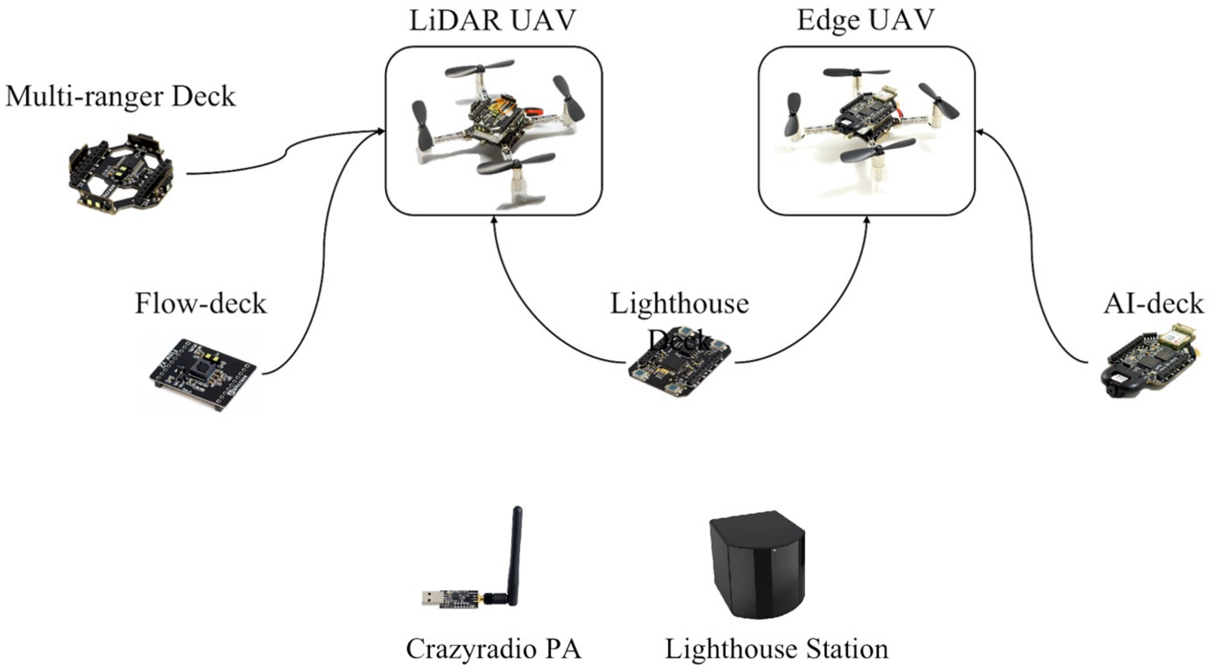
	parameters
platform	Crazyflie 2.1
Weigh	27g
Maximum load	15g
battery capacity	250mAh
size	$92\times92\times29mm$
MCU	Cortex-M4 (168MHz,192Kb SRAM,1Mb flash)

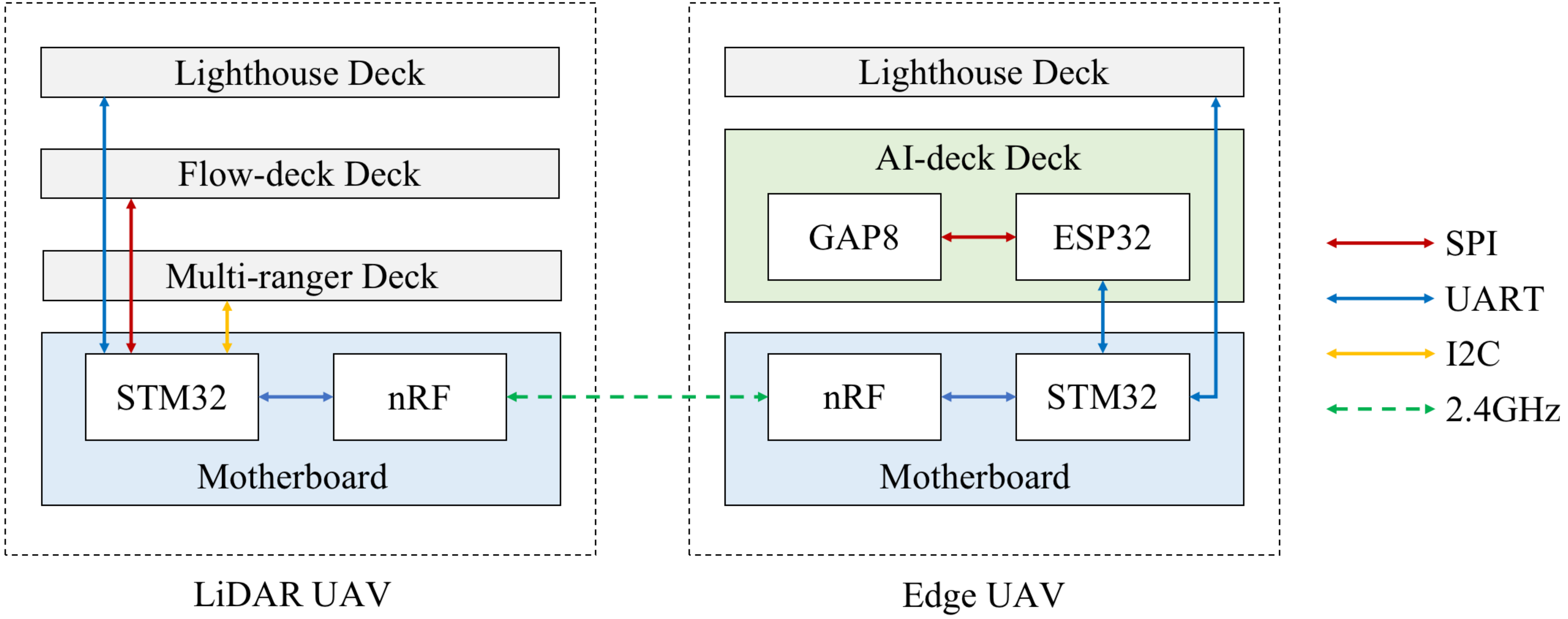
Experimental Deck

Deck	
Multi-ranger Deck	measures the distance to objects in different directions.
Flow-Deck	gives the Crazyflie the ability to detect its motions in any direction.
Lighthouse Deck	uses the base stations to achieve high precision positioning.
AI-deck	Make Crazyflie edge computing capable.
Crazyradio PA	It is a long range open USB radio dongle.

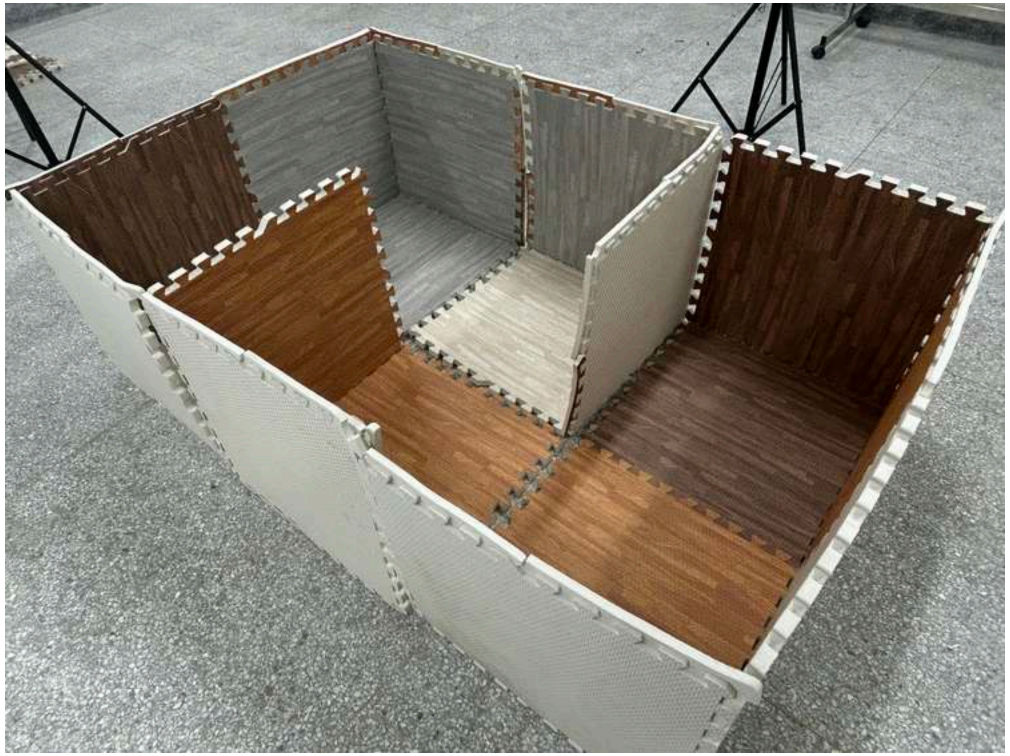


Communication Link

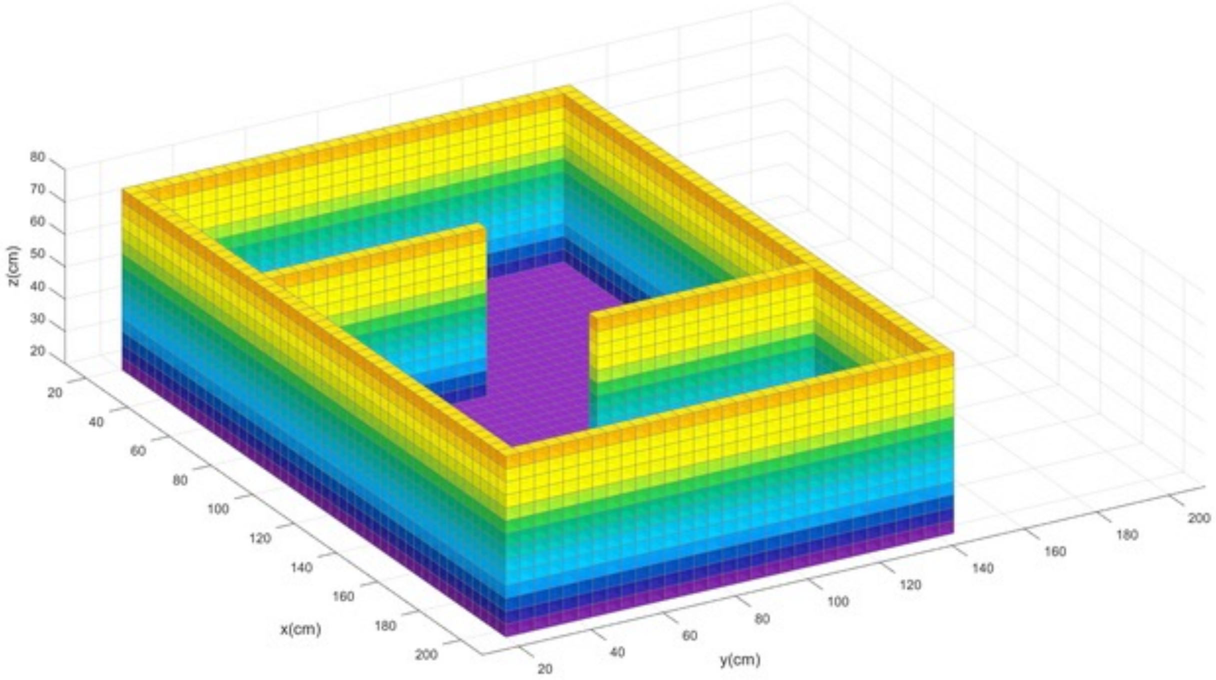
the inter-NAV and inter-board communication architecture:



Experimental map



Real map



Simulation map

Singal-NAV Simulation Result(4cm accuracy)

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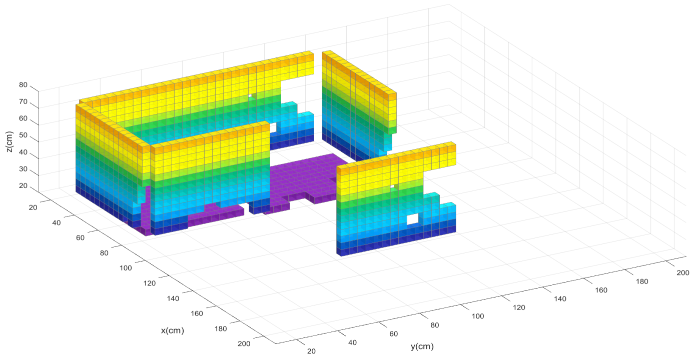
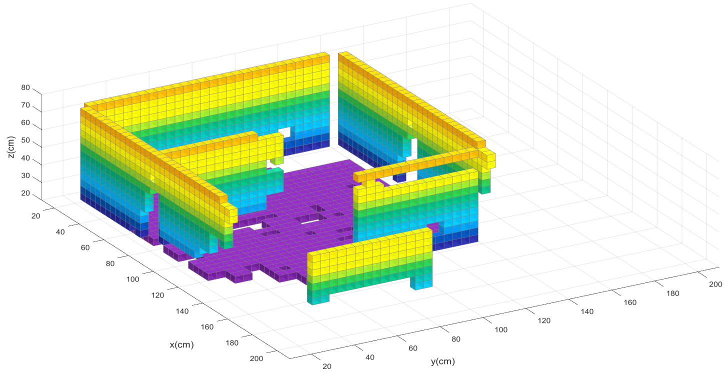
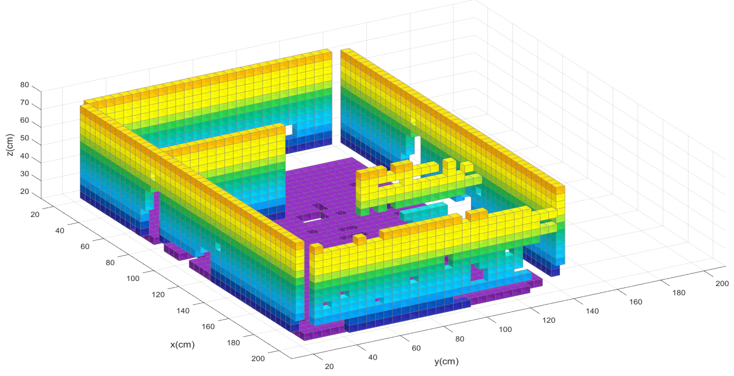
The effect of NAV mapping at different moments and the final flight path.



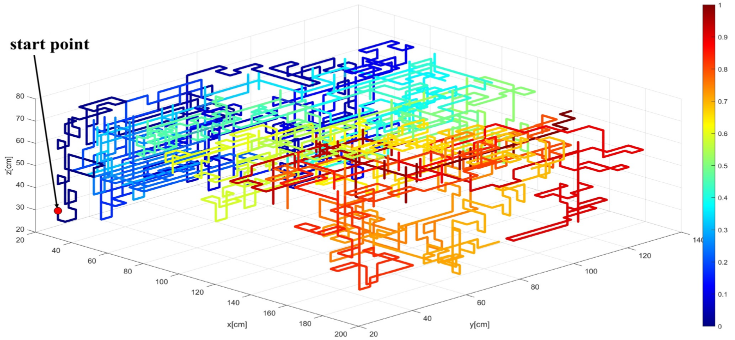
(a)Time = 300s



(b)Time = 650s



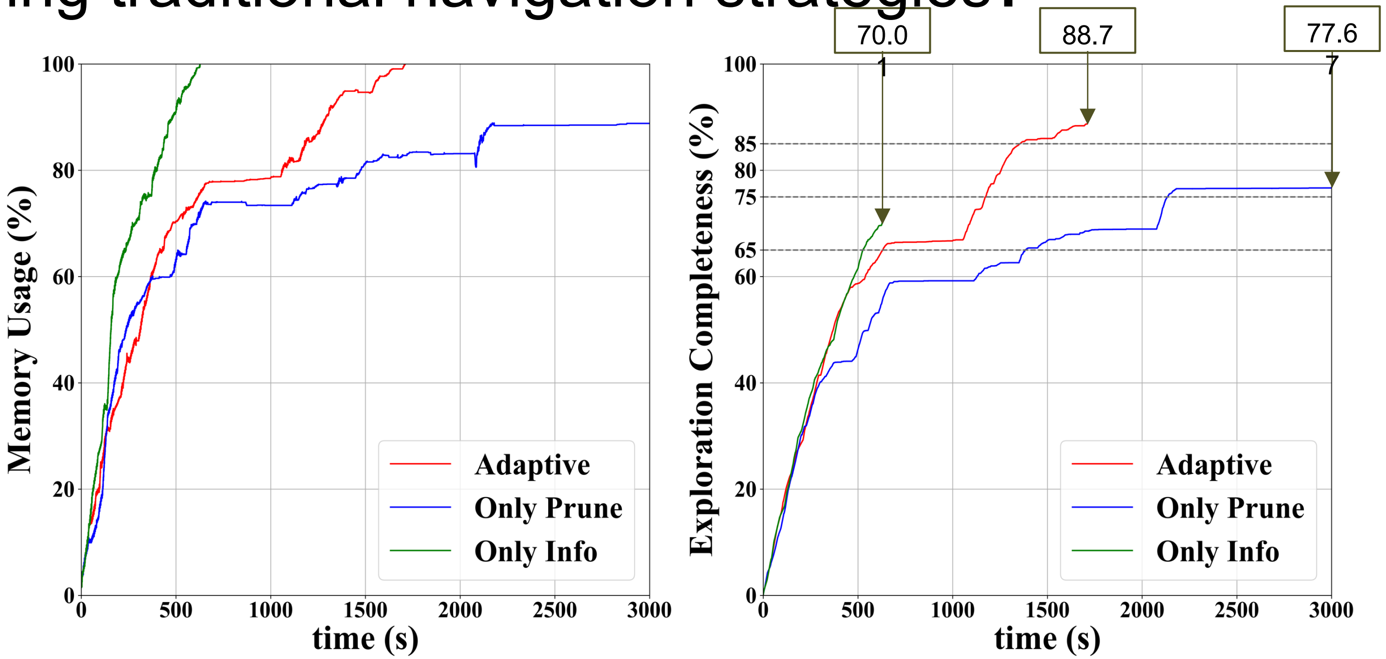
(c)Time = 1000s



(d)Flight path

Comparison of different exploration strategies(2cm accuracy)

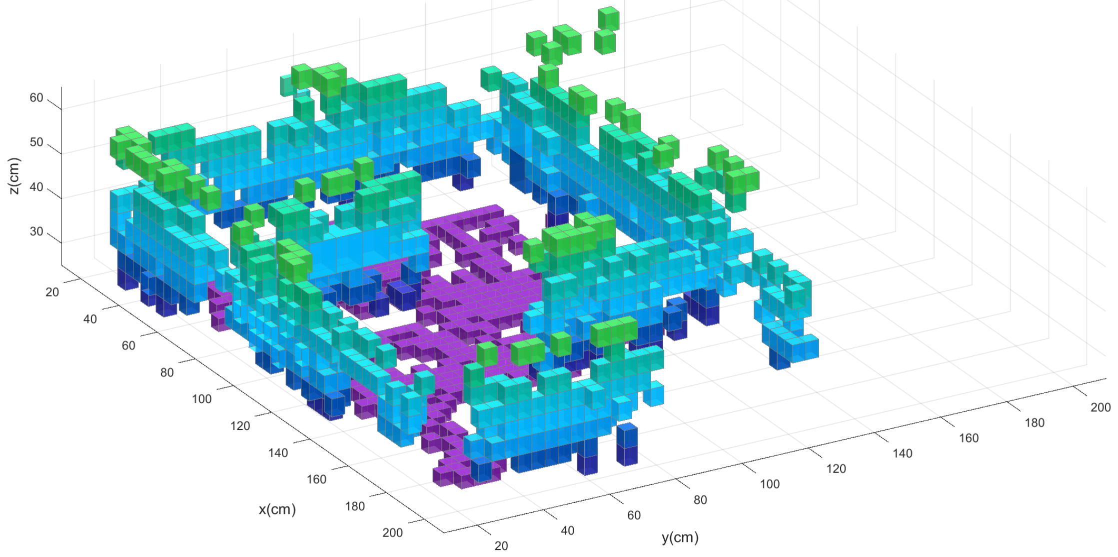
Results comparing traditional navigation strategies：



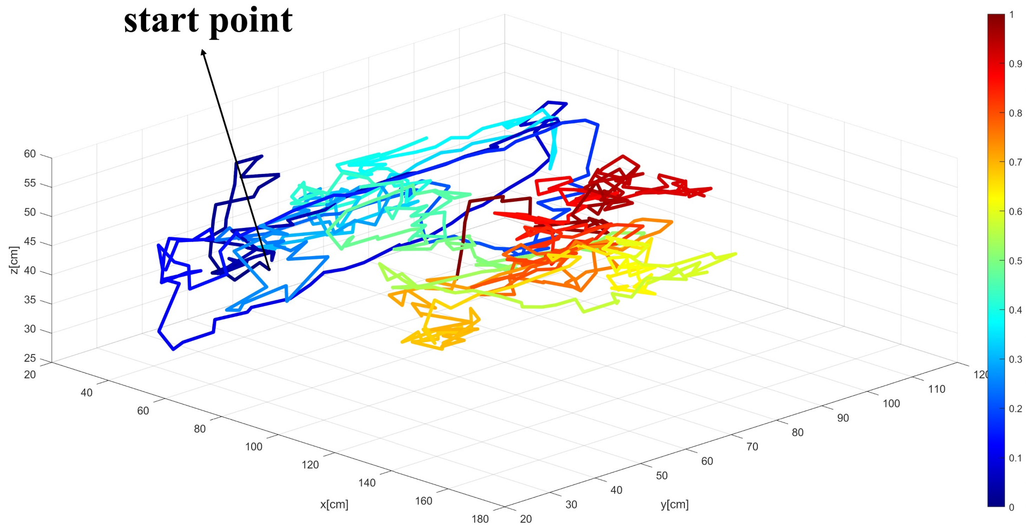
Strategies	65% exploration		75% exploration		85%exploration	
	Time(s)	%	Time(s)	%	Time(s)	%
Adaptive	633.5	100	1174	100	1354	100
Only Prune	526.5	82.11	∞	∞	∞	∞
Only Info	1382	218.19	2135	181.82	∞	∞

Single-NAV Real Result(4cm accuracy)

Real experimental results：

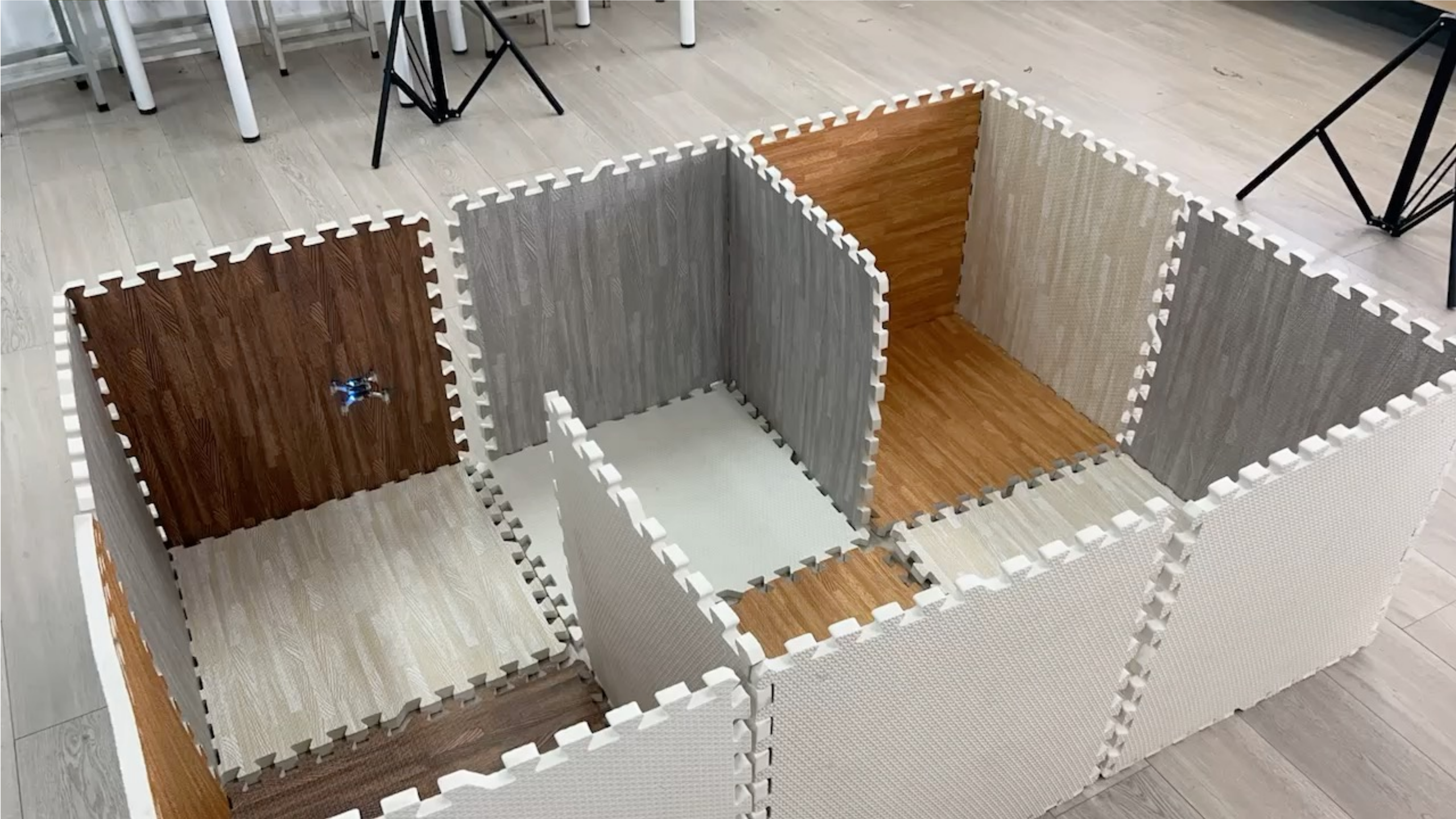


Time = 175s



Flight path

Due to NAV flight safety considerations, the NAV flight altitude needs to be at least 30 centimeters above the ground



Triple-NAVs Simulation Result(4cm accuracy)

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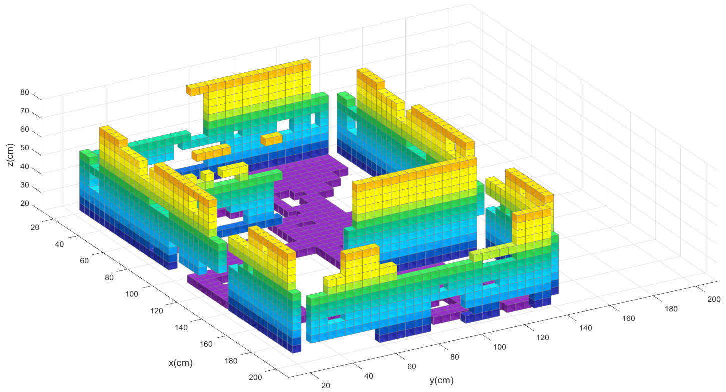
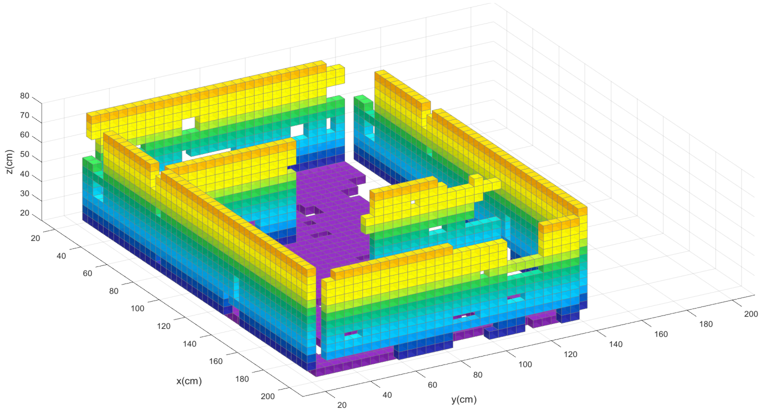
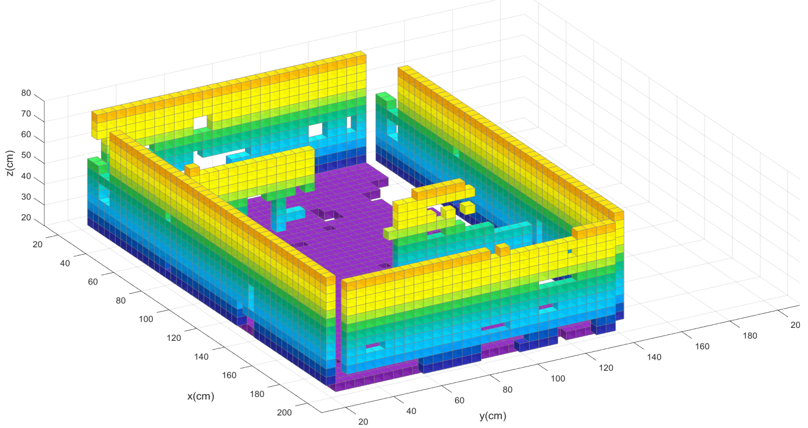
The effect of triple-NAVs mapping at different moments and the final Tricolor map.



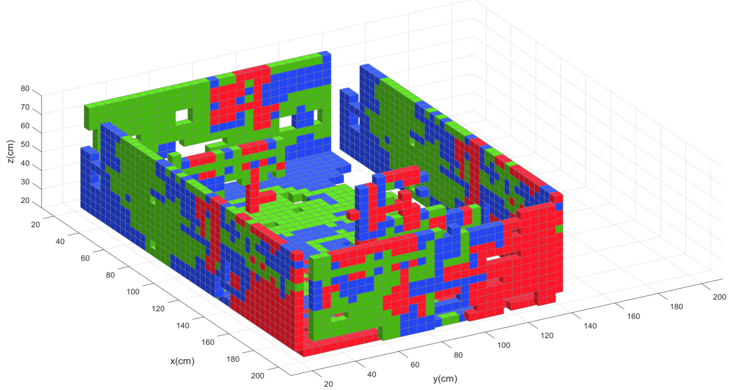
(a)Time = 100s



(b)Time = 200s

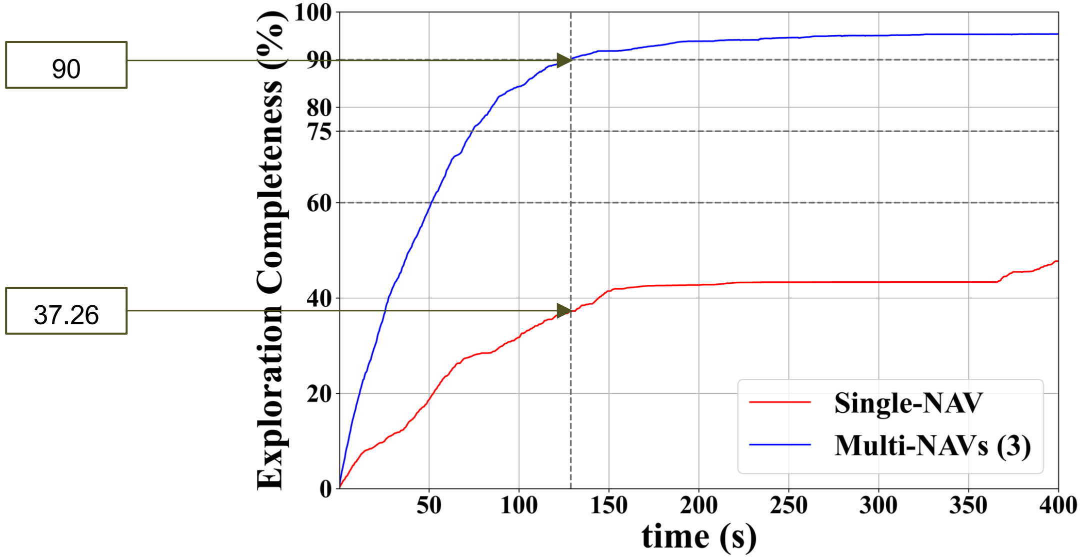


(c)Time = 400s



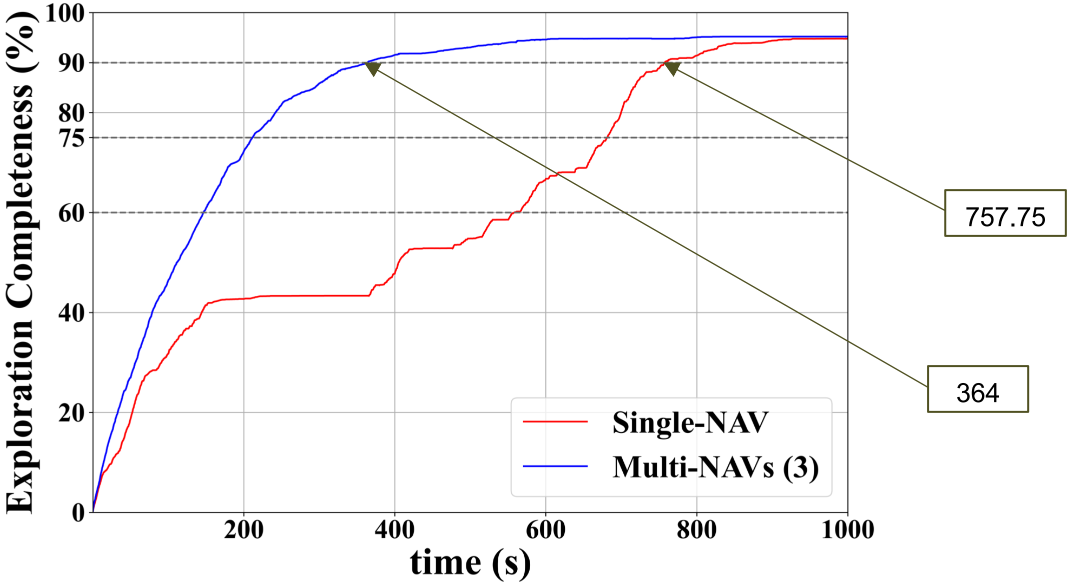
(d)Tricolor map

Results comparing single-NAV and triple-NAVs：



Same time

	Exploration completeness(%)
Single-NAV	37.26
Triple-NAVs	90

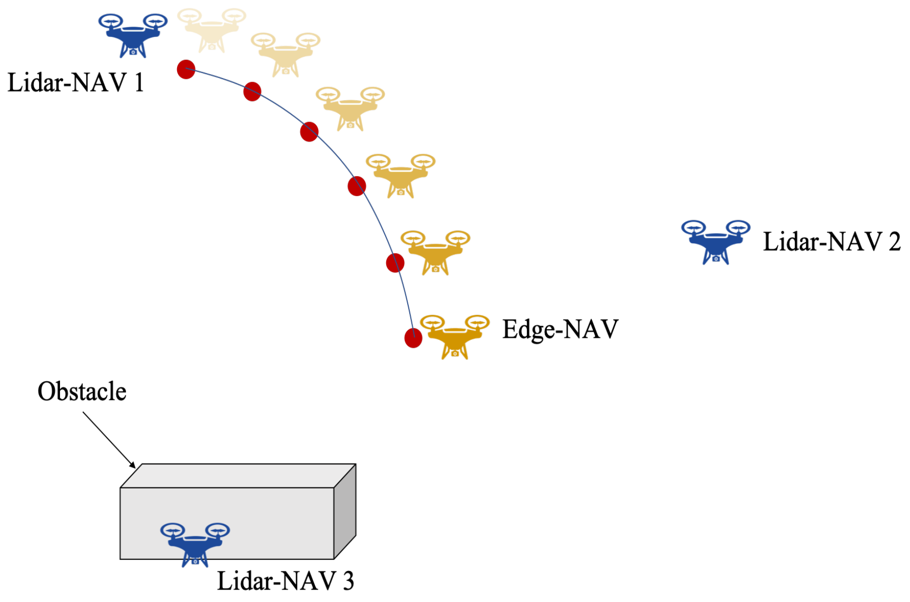


Same times

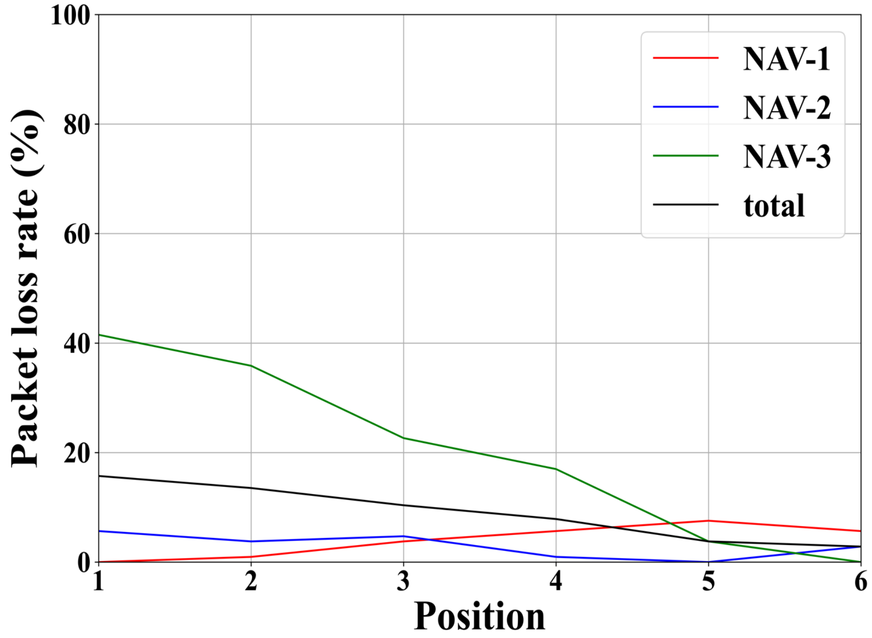
	90% exploration
	Time(s)
Single-NAV	757.75
Triple-NAVs	364

Triple-NAVs Real Result

Dynamically adjusting edge NAV using APF method results on packet loss rate:



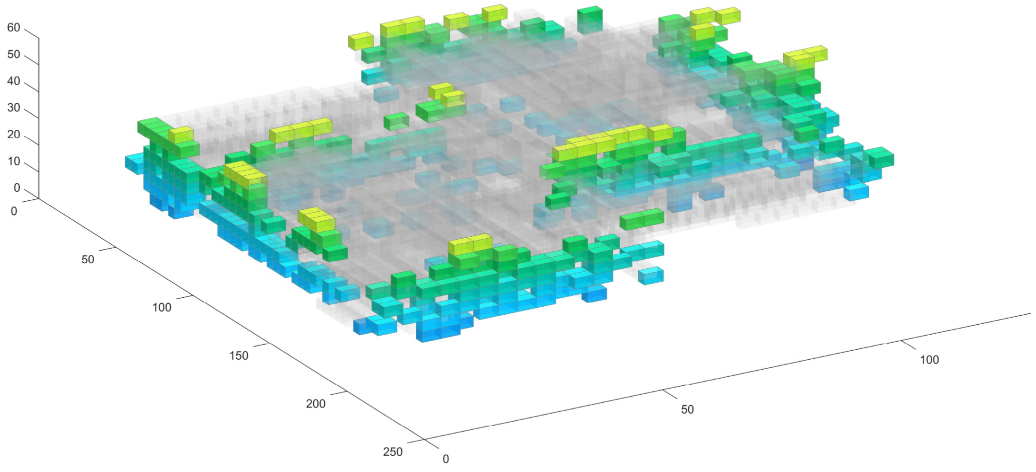
(a) Dynamic position



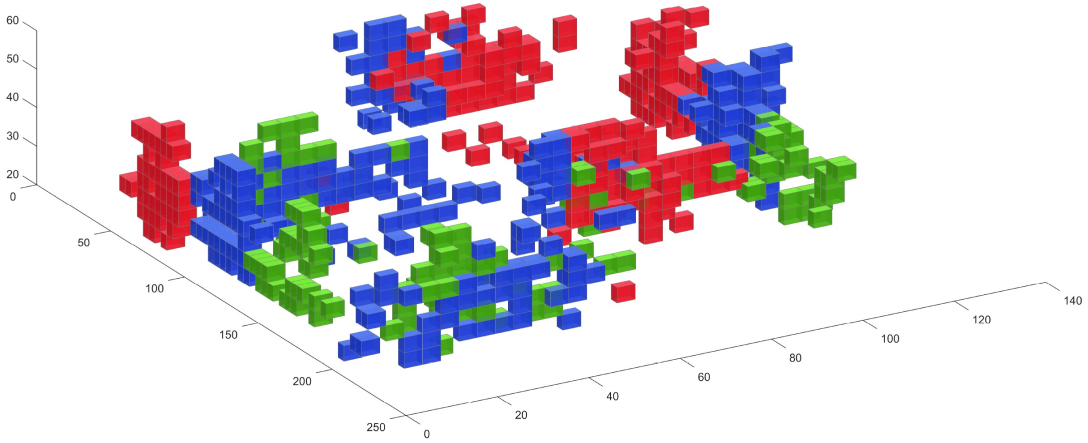
(b) Packet loss rate varies with different positions

Three-NAVs Real Result

Real experimental results：



Time = 30s



Tricolor map

Gray squares represent known areas.

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PART SIX

Conclusion

Conclusion

In this paper, we propose a cooperative NAV system using heterogeneous NAVs for autonomous mapping in unknown and confined environments. The main tasks are as follows:

- We propose an improved map model: TinyOctomap.
- We propose the active exploration strategy, which improves memory usage efficiency while ensuring exploration efficiency.
- We design an efficient computing offloading strategy.
- We have conducted a large number of simulations and real experiments to verify the robustness and effectiveness of the system.

Thanks for your listening!

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