

# H-SwarmLoc: Efficient Scheduling for Localization of Heterogeneous MAV Swarm with Deep Reinforcement Learning

Haoyang Wang<sup>1\*</sup>, Xuecheng Chen<sup>1\*</sup>, Yuhang Cheng<sup>1</sup>, Chenye Wu<sup>2</sup>, Fan Dang<sup>1</sup>, Xinlei Chen<sup>1</sup>  
Tsinghua University<sup>1</sup>, The Chinese University of Hong Kong, Shenzhen<sup>2</sup>



TBSI

清华-伯克利深圳学院  
Tsinghua-Berkeley Shenzhen Institute



粤港澳大湾区博士生南山学术论坛  
暨清华大学第706期博士生学术论坛



香港中文大學(深圳)  
The Chinese University of Hong Kong, Shenzhen

# Situational Awareness Sensing in Dangerous Areas

Allows rescuers to draw up effective strategies to minimize the loss of life



Gas Leak



Forest Fire



Nuclear Radiation



Earthquakes

# Situational Awareness Sensing in Dangerous Areas

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Xichang, Sichuan, China  
2022 March, **19 death**



Muli, Sichuan, China  
2019 Marth, **30 death**



Nuclear Radiation



Earthquakes



safe routes?  
dangerous areas?  
locations of survivors?

<https://www.bbc.com/zhongwen/simp/chinese-news-52208183>

# Situational Awareness Sensing in Dangerous Areas

Allows rescuers to draw up effective strategies to minimize the loss of life



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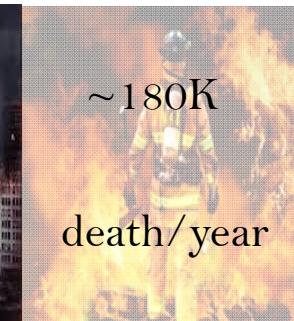
Muli, Sichuan, China  
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Nuclear Radiation



Earthquakes



safe routes?

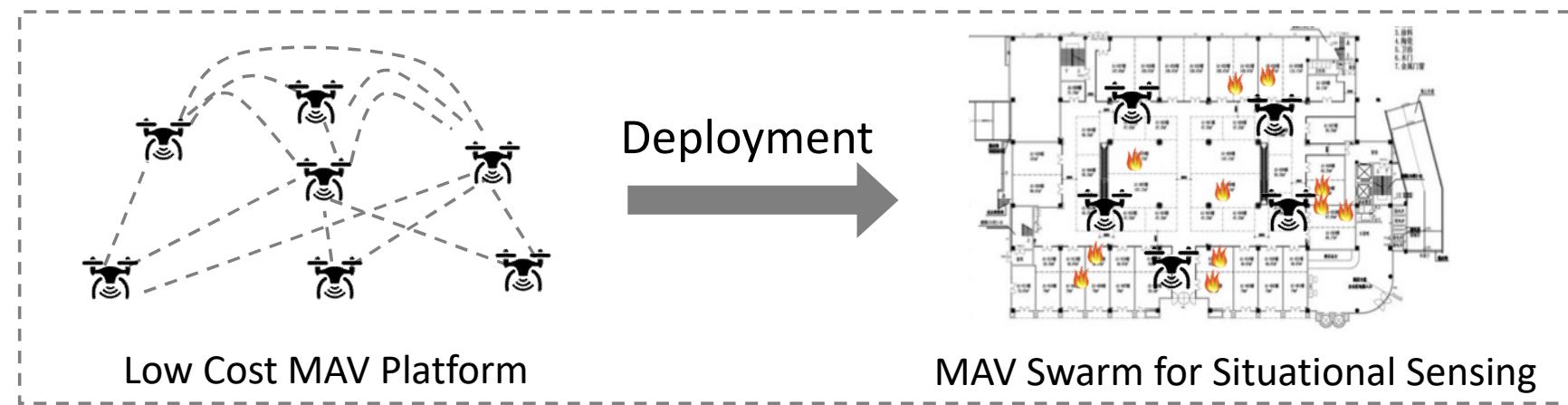
dangerous areas?

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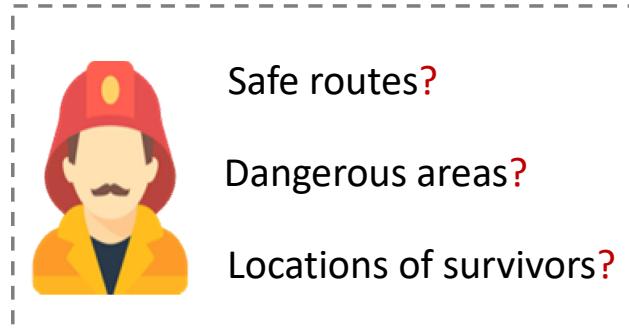
Need for **Fine-grained Real-time** environmental info.

# Opportunity: MAV Swarm

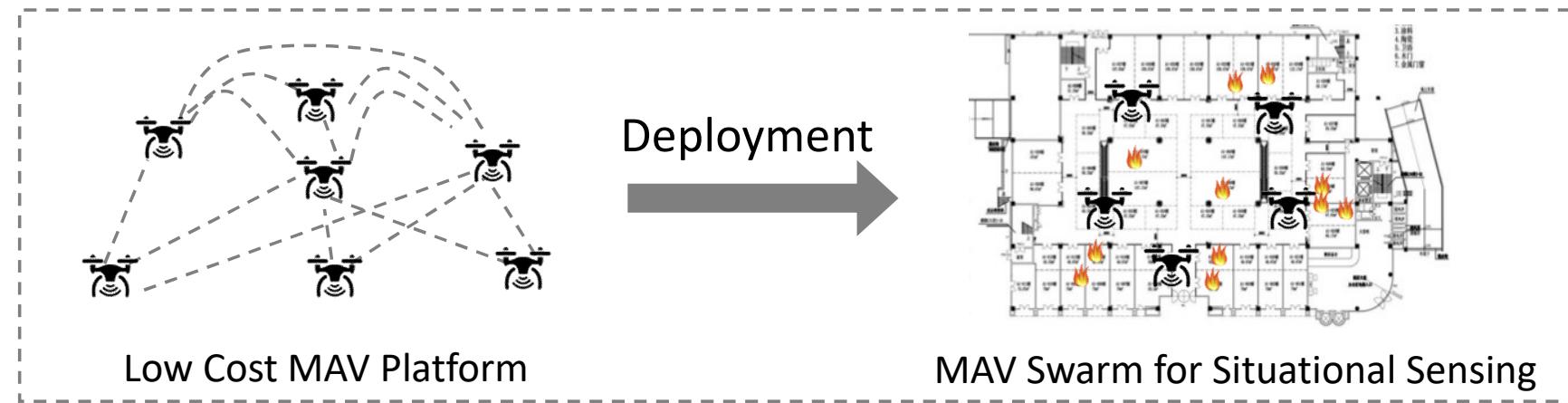
**Deploy sensing capabilities** at key areas in search & rescue



# Opportunity: MAV Swarm



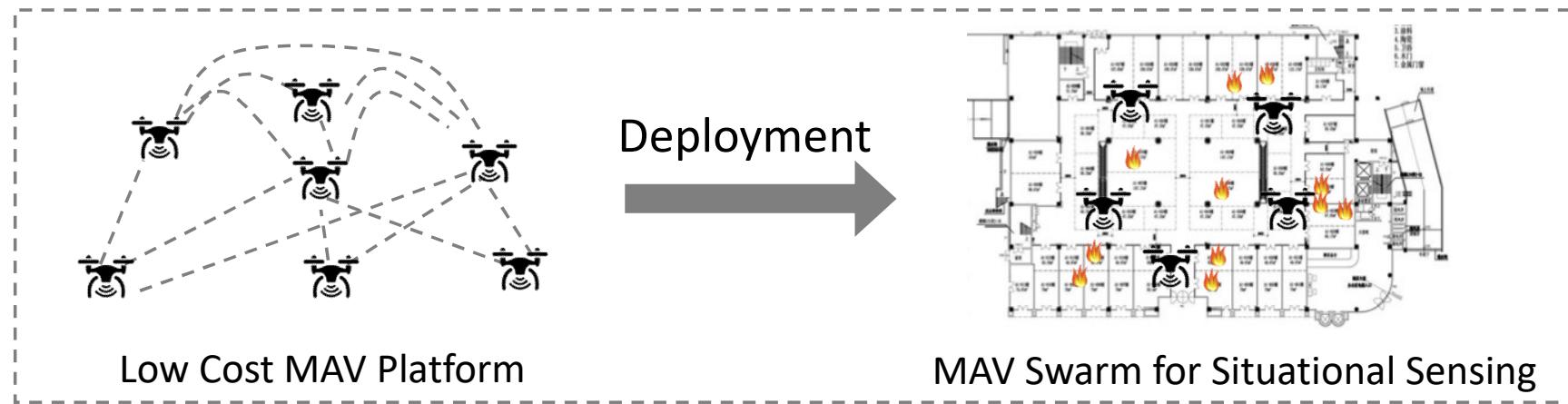
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# Opportunity: MAV Swarm



**Deploy sensing capabilities** at key areas in search & rescue



# Crucial Step: Accurate localization



## Accurate Localization

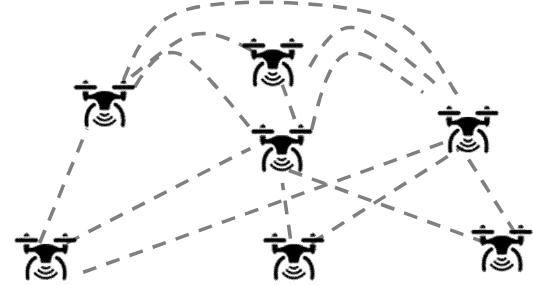


# Crucial Step: Accurate localization

Accurate Localization

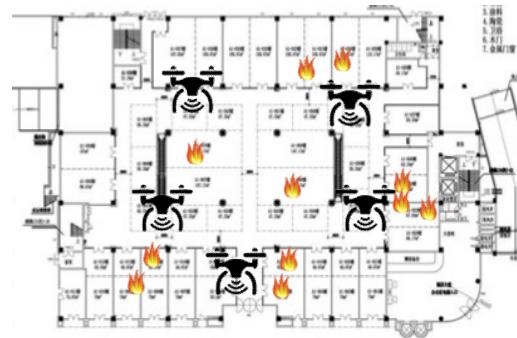


Efficient Navigation



Low Cost MAV Platform

Deployment



MAV Swarm for Situational Sensing

# Crucial Step: Accurate localization

Accurate Localization



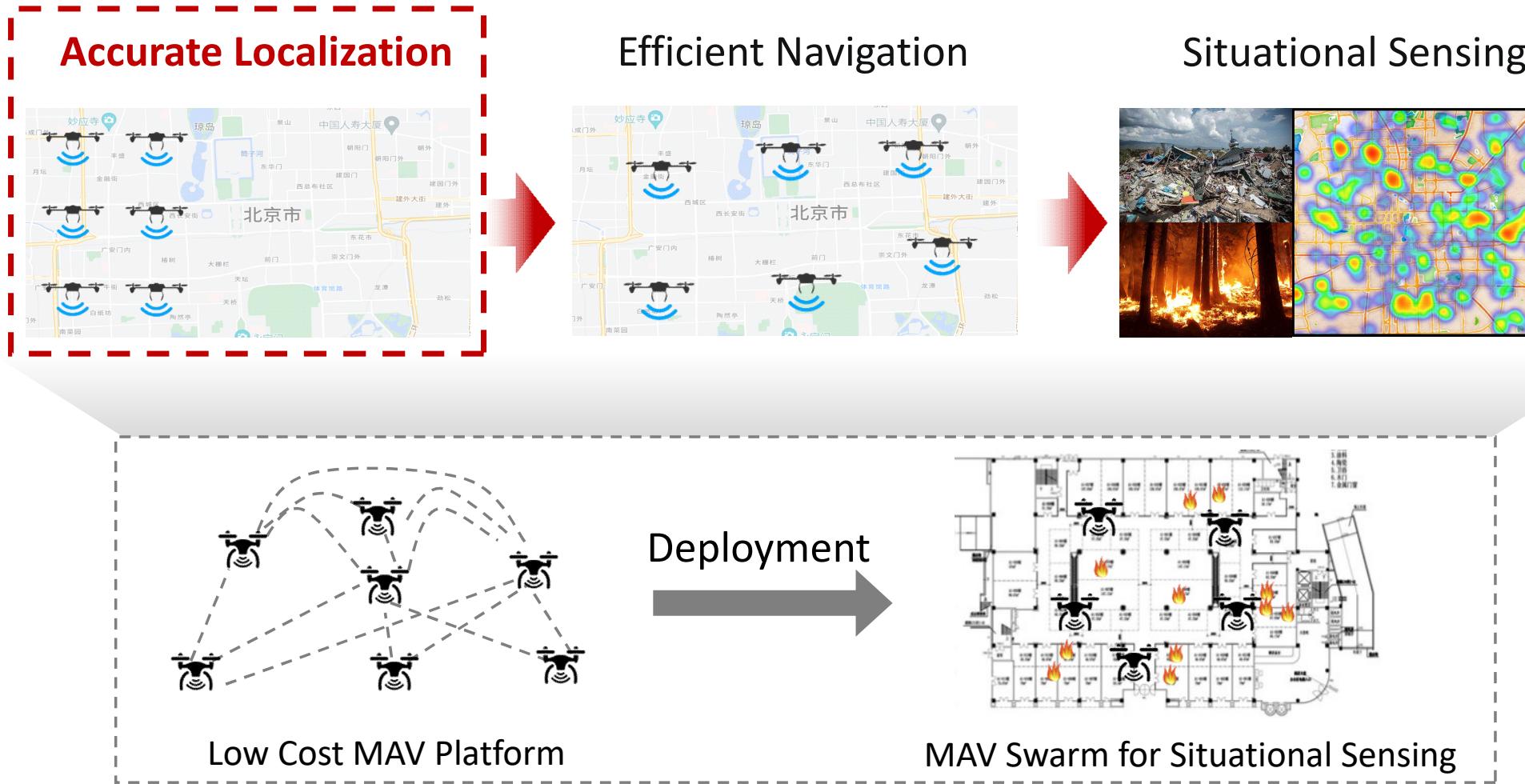
Efficient Navigation



Situational Sensing



# Crucial Step: Accurate localization



# Crucial Step: Accurate localization

## ➤ Onboard Capabilities

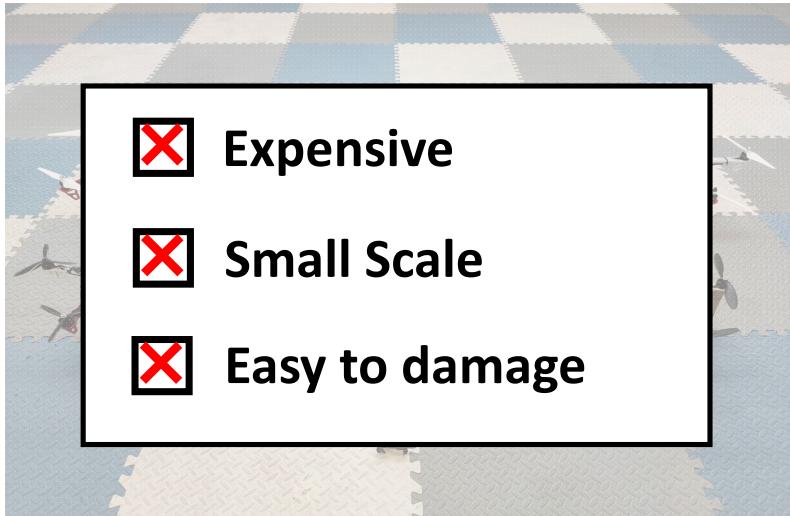
- *Depth cameras*
- *Lidars*



# Crucial Step: Accurate localization

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- *Lidars*

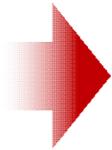
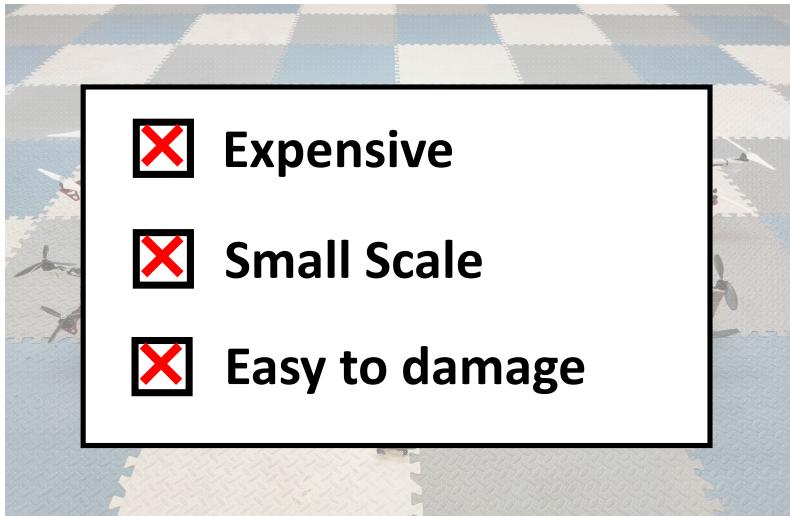


Hard to be extended to large scale swarm

# Crucial Step: Accurate localization

## ➤ Onboard Capabilities

- Depth cameras
- Lidars



## ➤ Extra Localization Infrastructure

- Global Positioning System
- Motion Capture System

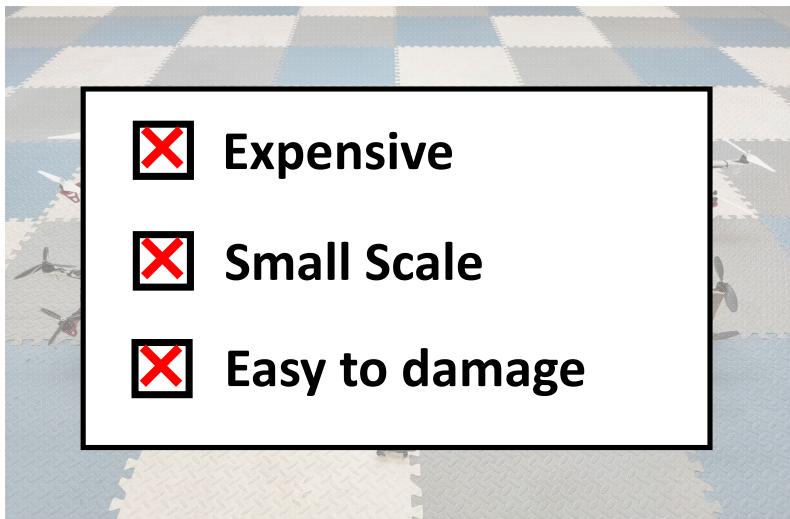


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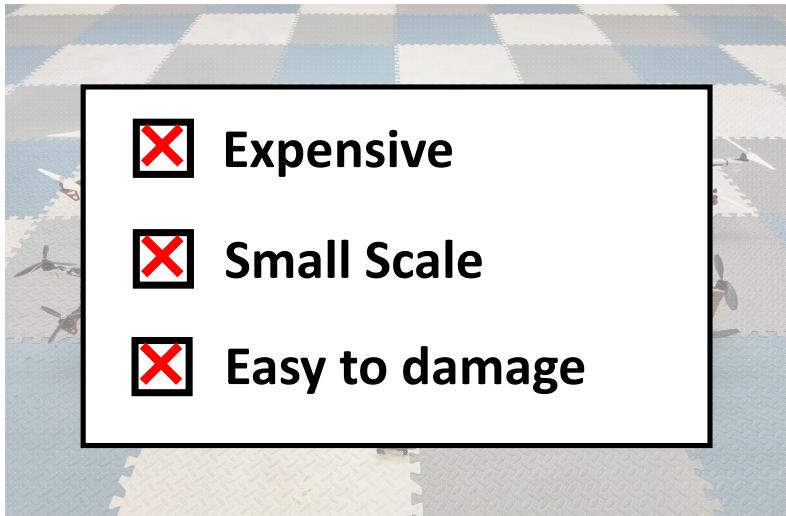


Hard to be used in dangerous scenarios

# Crucial Step: Accurate localization

## ➤ Onboard Capabilities

- *Depth cameras*
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Hard to be extended to large scale swarm

## ➤ Extra Localization Infrastructure

- *Global Positioning System*
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Hard to be used in dangerous scenarios

**Not suitable** for MAV swarm used in disaster scenarios

# The Research Objective

Challenge 1

Low-cost large-scale MAV swarm



Challenge 2

No extra localization infrastructure

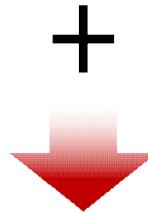
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Accomplish precise localization for whole swarm

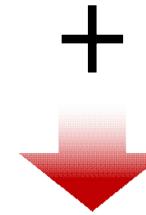
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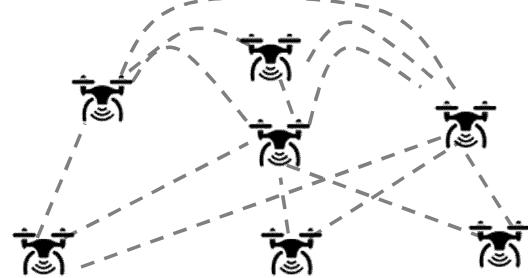
Low-cost large-scale MAV swarm

Challenge 2

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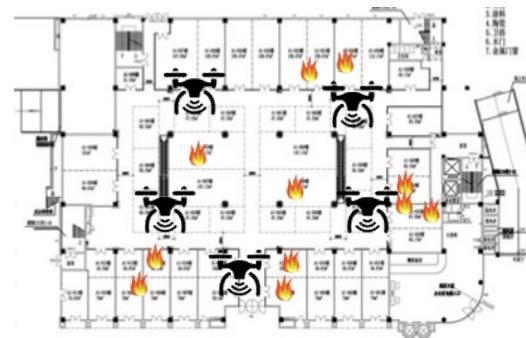


Accomplish precise localization for whole swarm



Low Cost Tiny MAV Platform

Deployment



MAV Swarm for Situational Sensing

# Our Proposed MAV Swarm System

## Basic Components



Advanced MAV

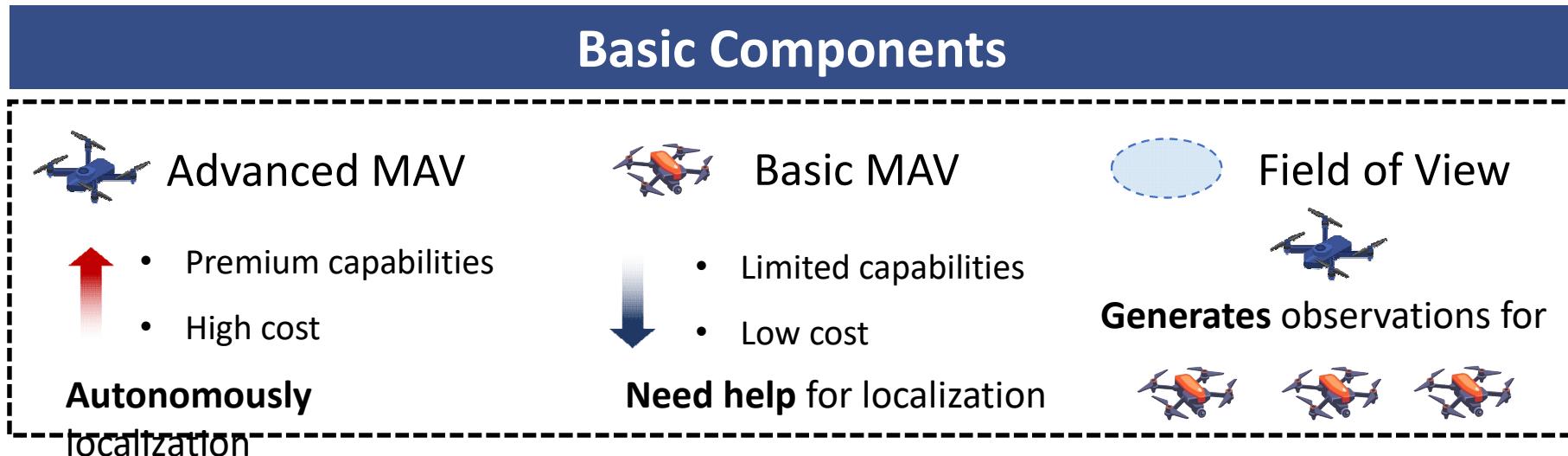


Basic MAV



Field of View

# Our Proposed MAV Swarm System



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## Basic Components



Advanced MAV



Basic MAV



Field of View

## Interaction Relationship



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Basic MAV



Field of View

## Interaction Relationship



Velocity data from IMU



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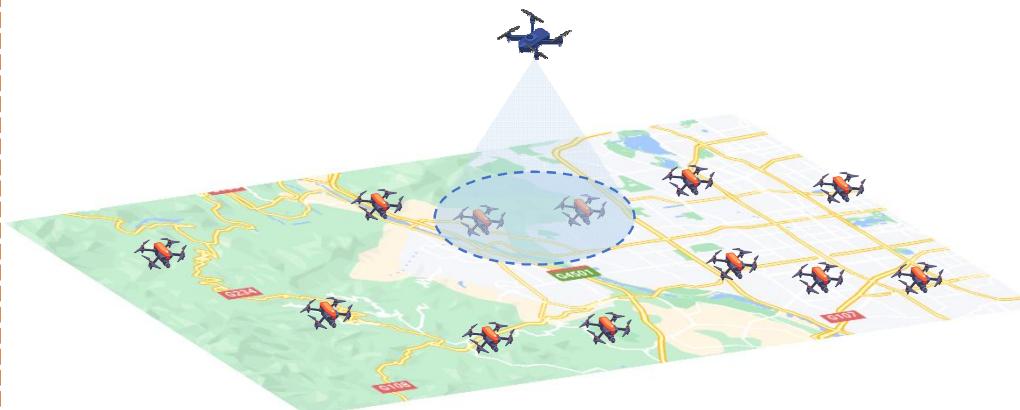


Basic MAV



Field of View

## Interaction Relationship



Velocity data from IMU

+



Observation from Camera

# Our Proposed MAV Swarm System

## Basic Components



Advanced MAV



Basic MAV



Field of View

## Interaction Relationship



Velocity data from IMU

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Observation from Camera

||

**Accurate localization**  
of several BMAVs

# Our Proposed MAV Swarm System

## Basic Components



Advanced MAV

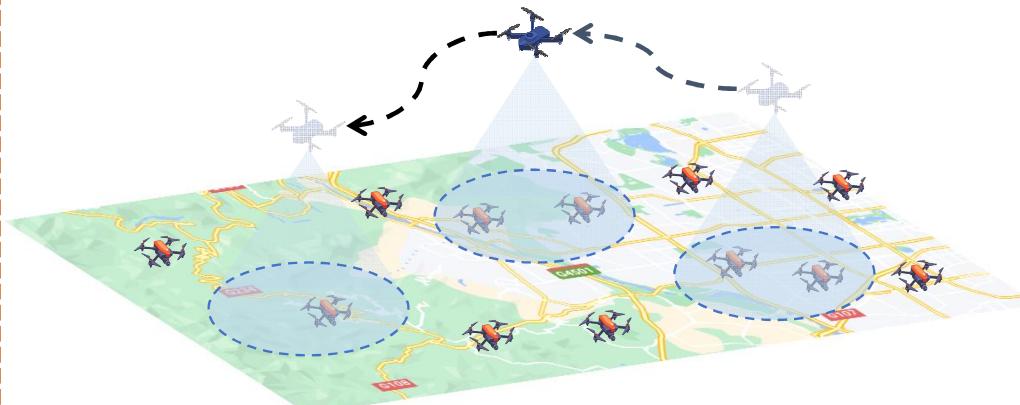


Basic MAV



Field of View

## Interaction Relationship



Velocity data from IMU

+



Observation from Camera

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Planning to observe BMAVs

# Our Proposed MAV Swarm System

## Basic Components



Advanced MAV

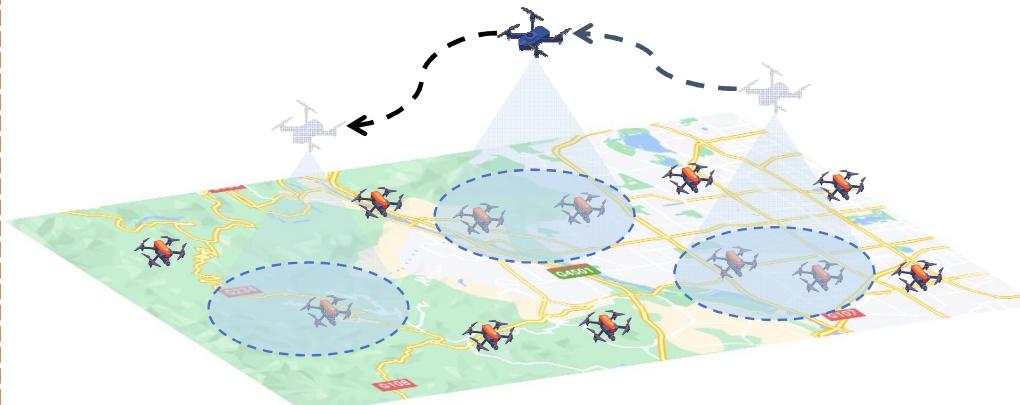


Basic MAV



Field of View

## Interaction Relationship



Velocity data from IMU

+



Observation from Camera

+

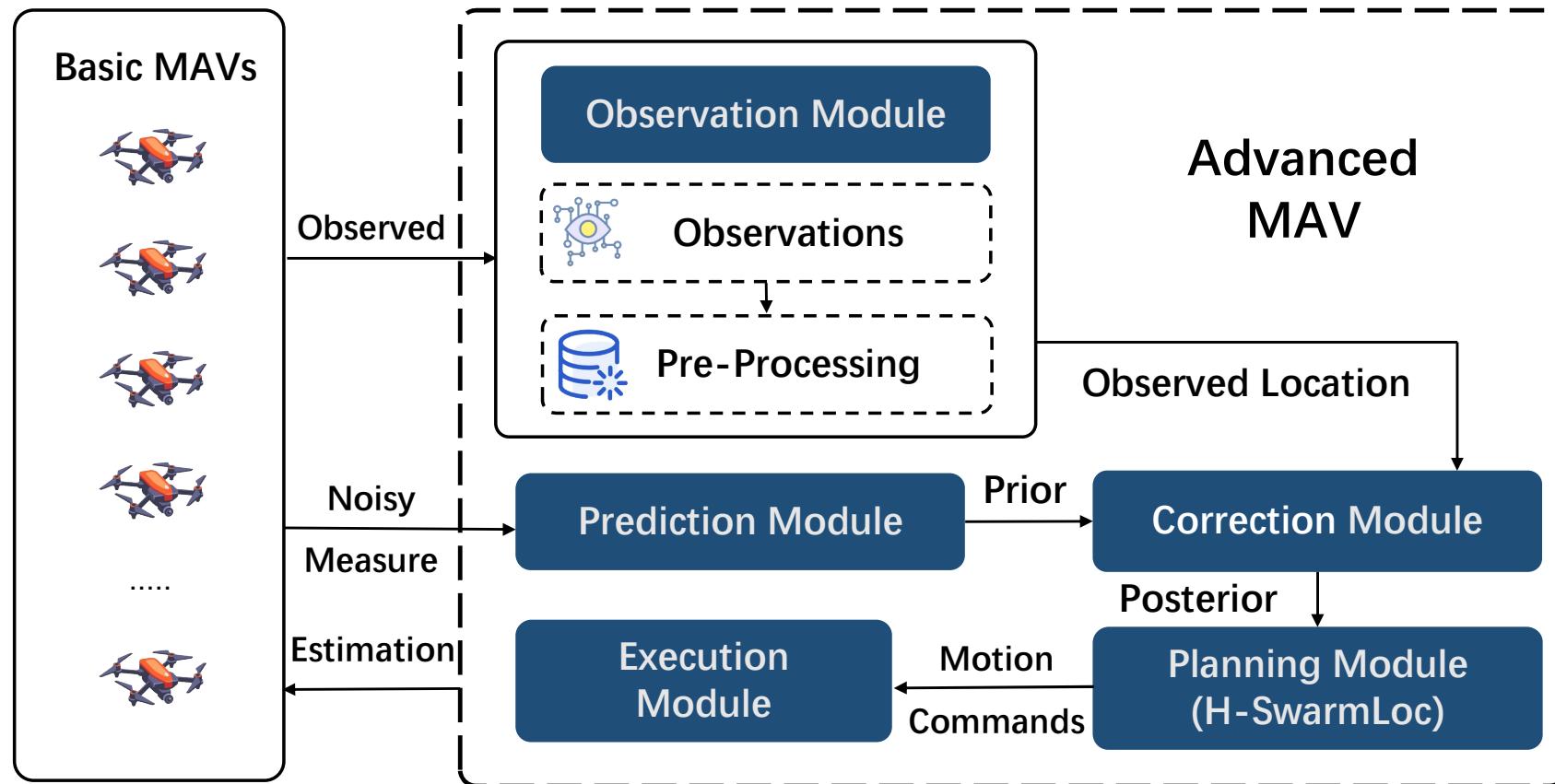


Planning to observe BMAVs

||

**Accurate localization** of whole system

# Our Proposed Drone Swarm System



# Our Proposed MAV Swarm System

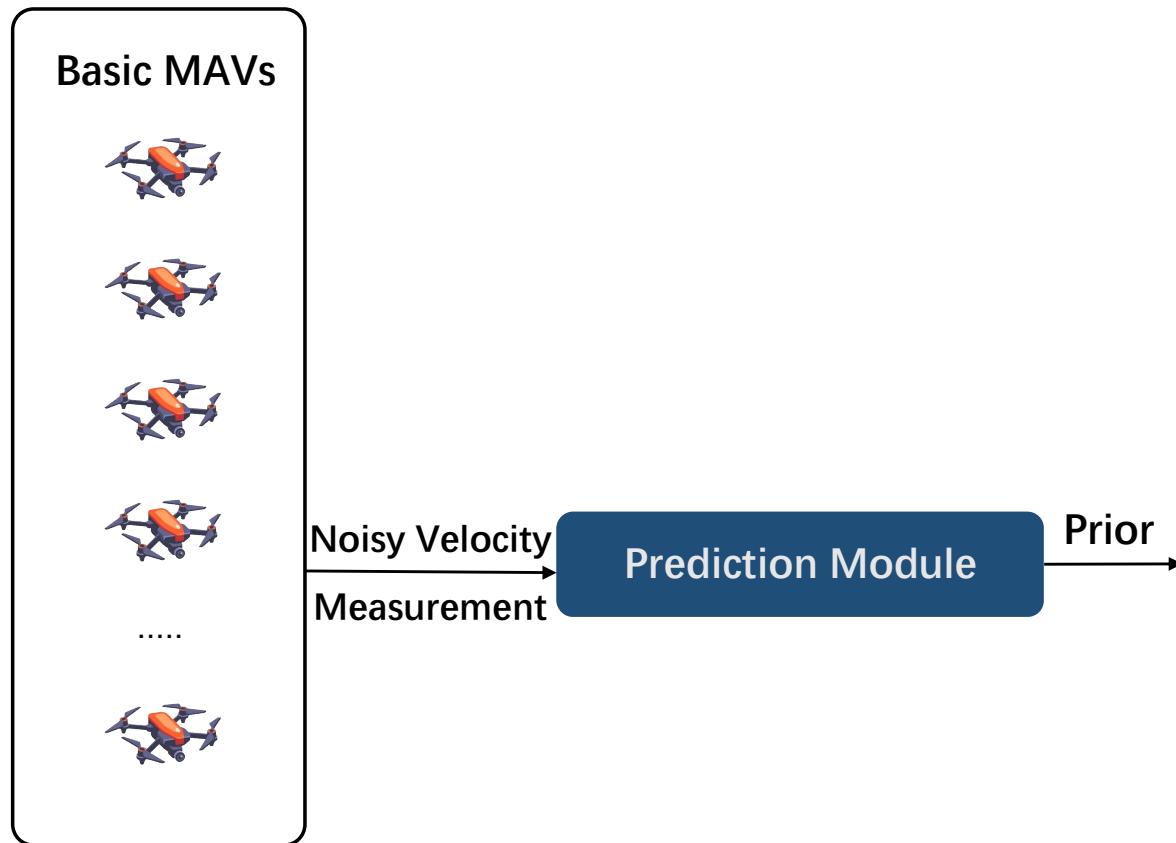
Basic MAVs



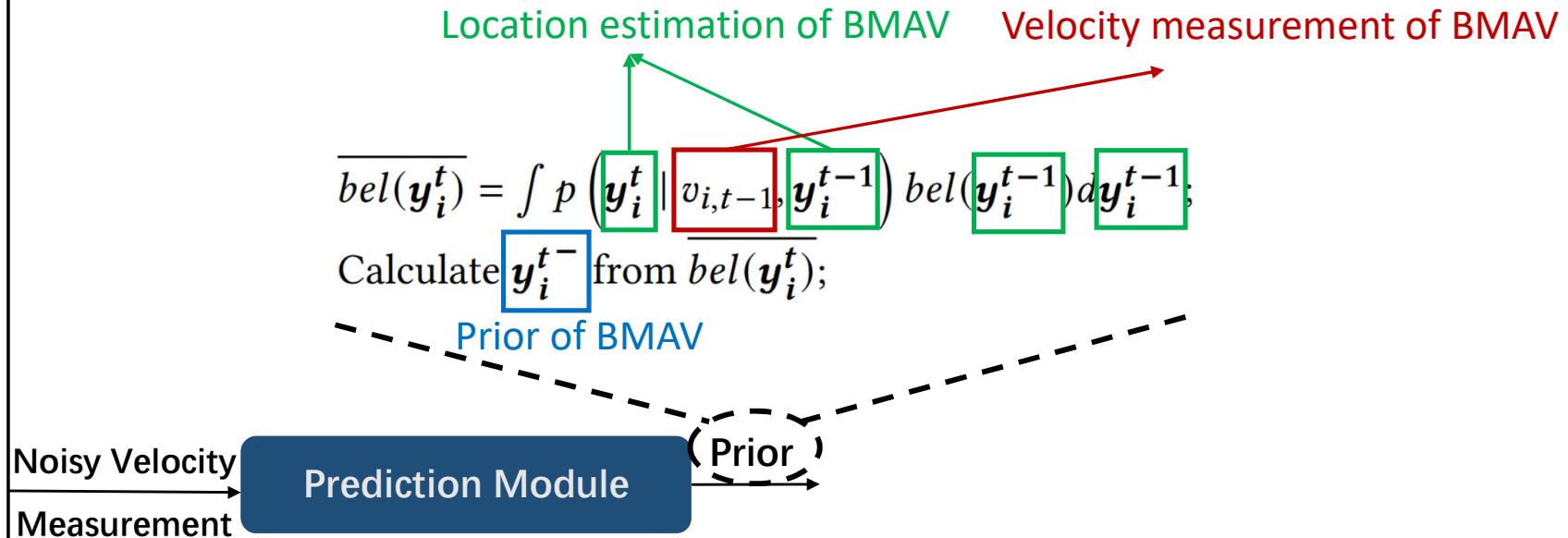
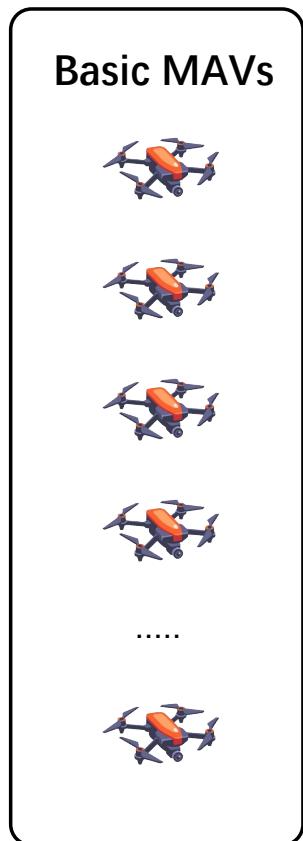
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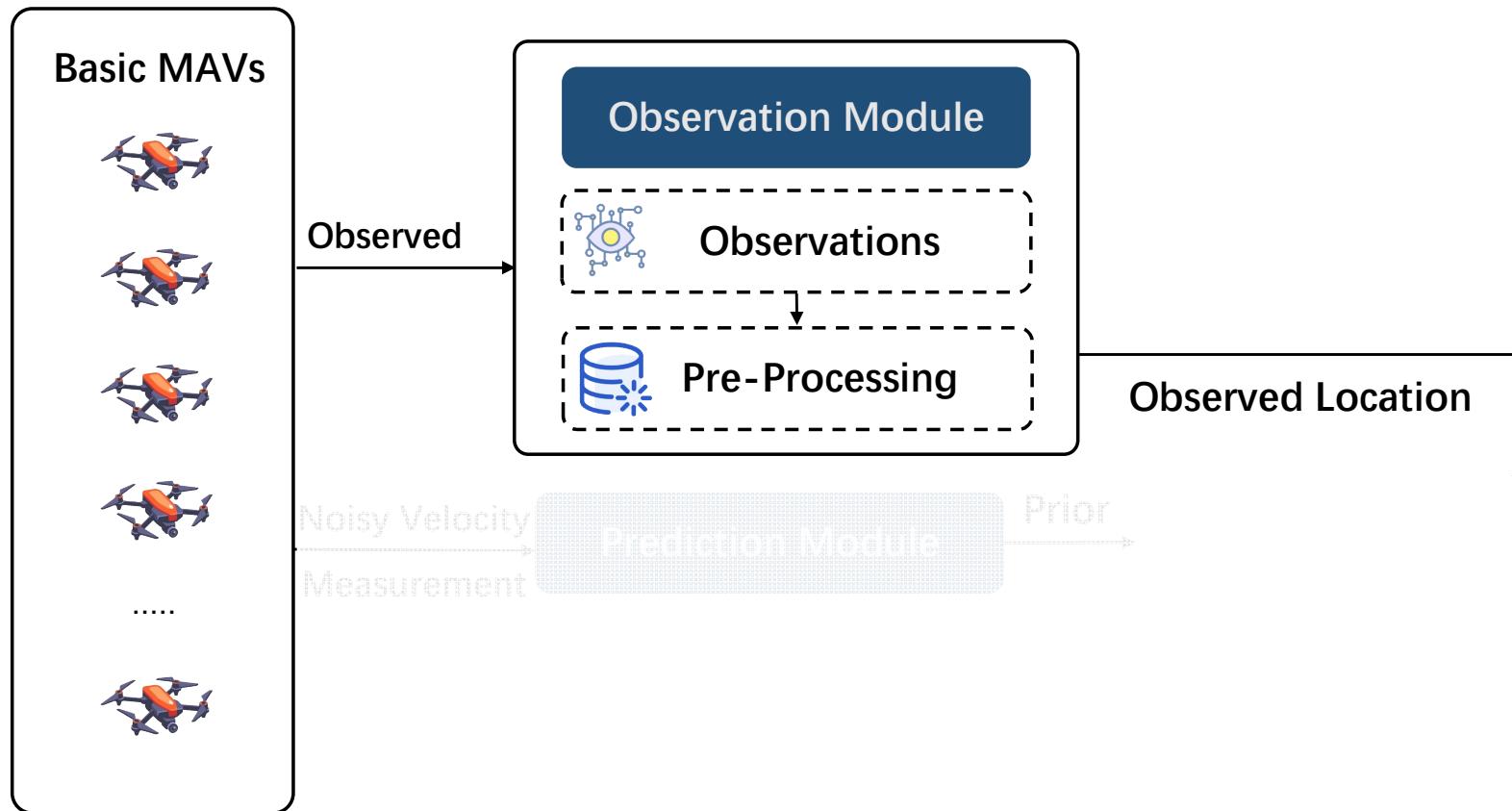
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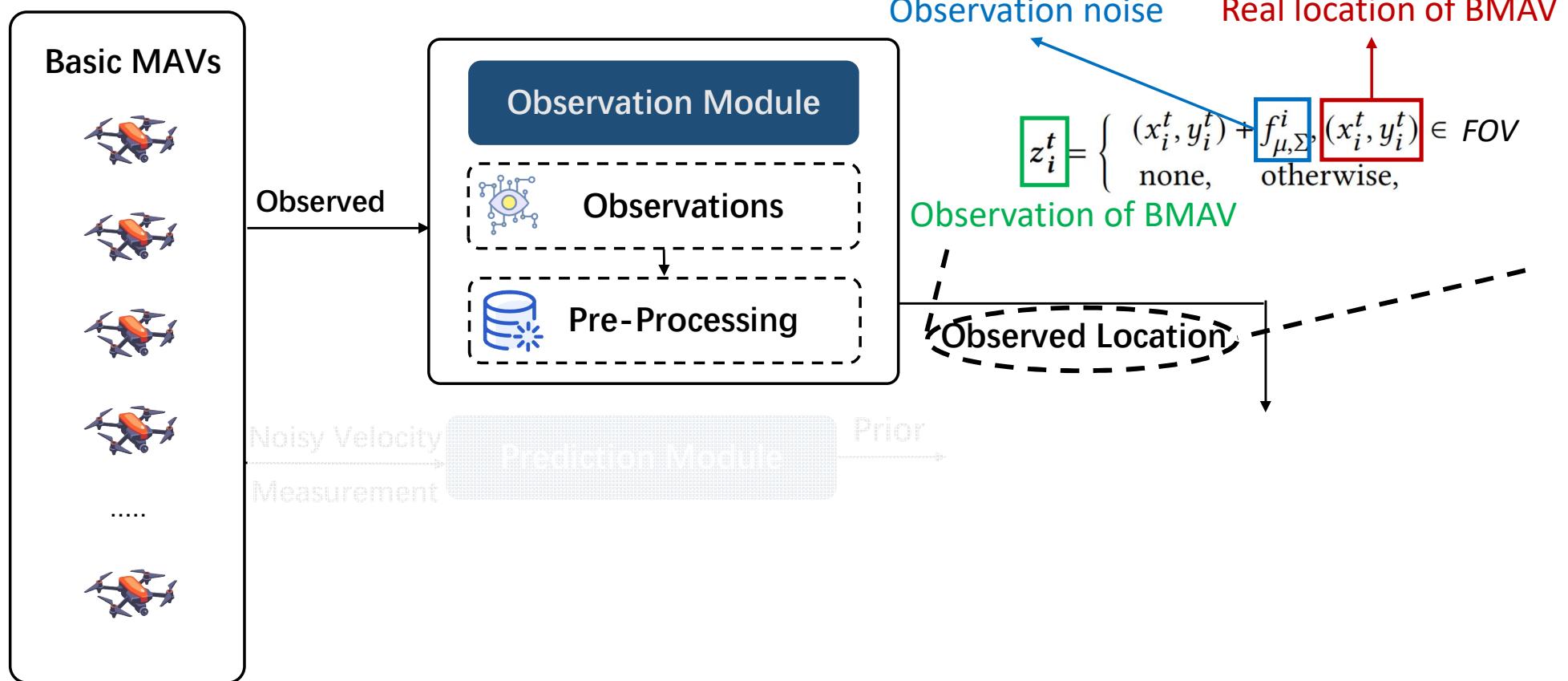
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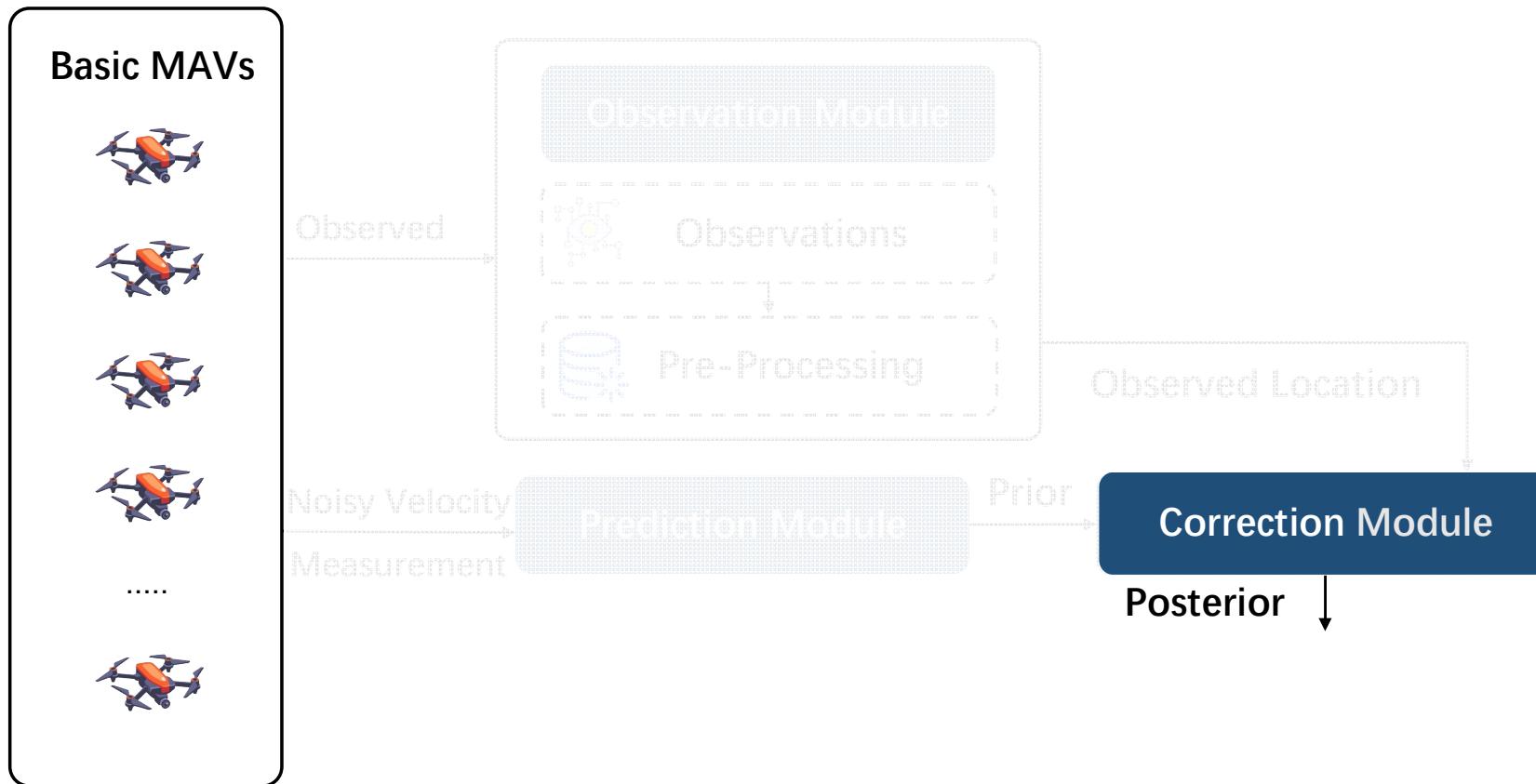
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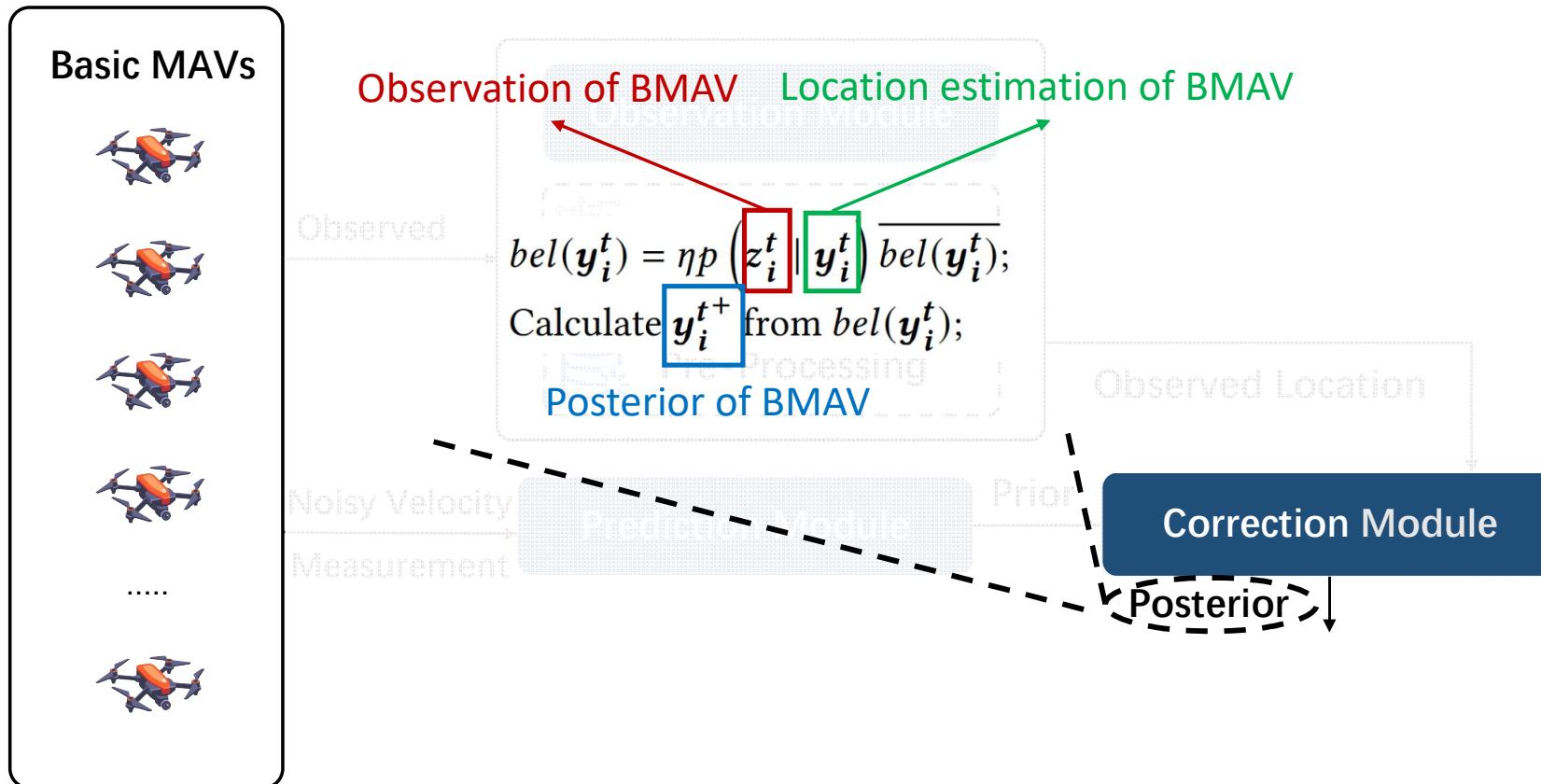
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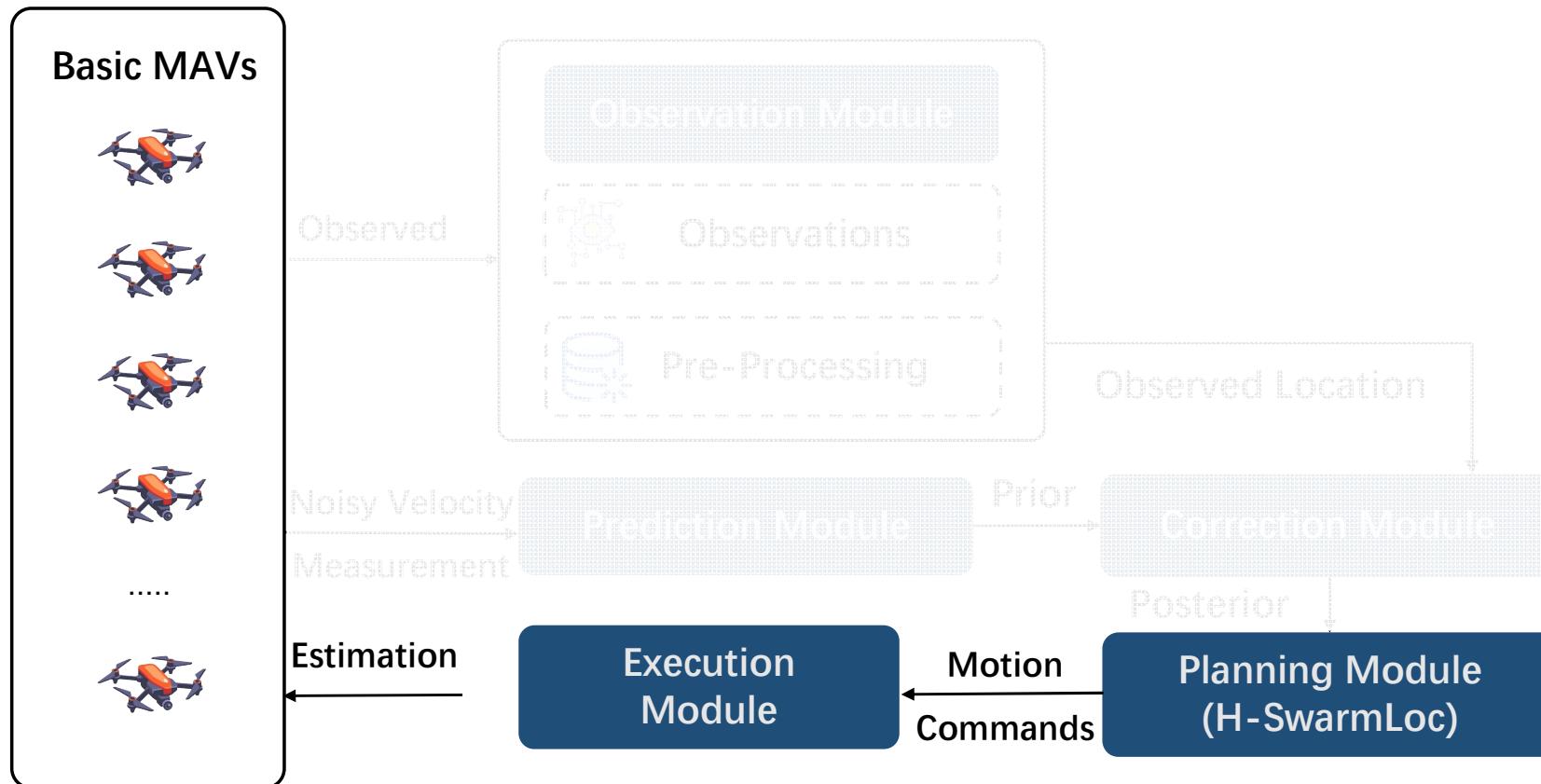
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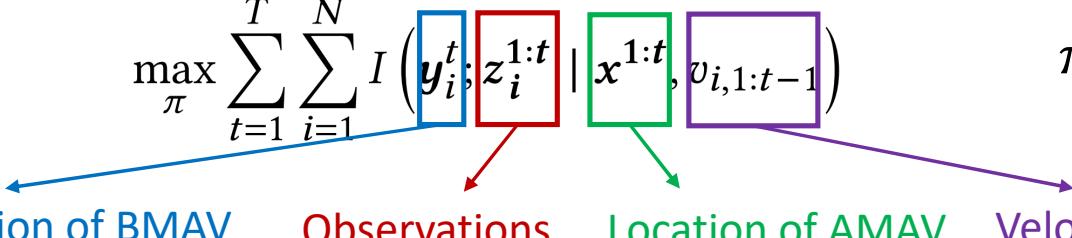
# Planning Module: H-SwarmLoc

- Objective: maximize mutual information between actual location and observations

$$\max_{\pi} \sum_{t=1}^T \sum_{i=1}^N I(\mathbf{y}_i^t; \mathbf{z}_i^{1:t} | \mathbf{x}^{1:t}, \mathbf{v}_{i,1:t-1})$$

$\pi$ : Actions sequence of AMAV

Actual location of BMAV      Observations      Location of AMAV      Velocity measurement of BMAV



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Actual location of BMAV    
 Observations    
 Location of AMAV    
 Velocity measurement of BMAV

$\pi$ : Actions sequence of AMAV

s.t.

$$0 \leq x_i^t, x_a^t \leq L, t = 0, \dots, T, i = 1, \dots, N$$

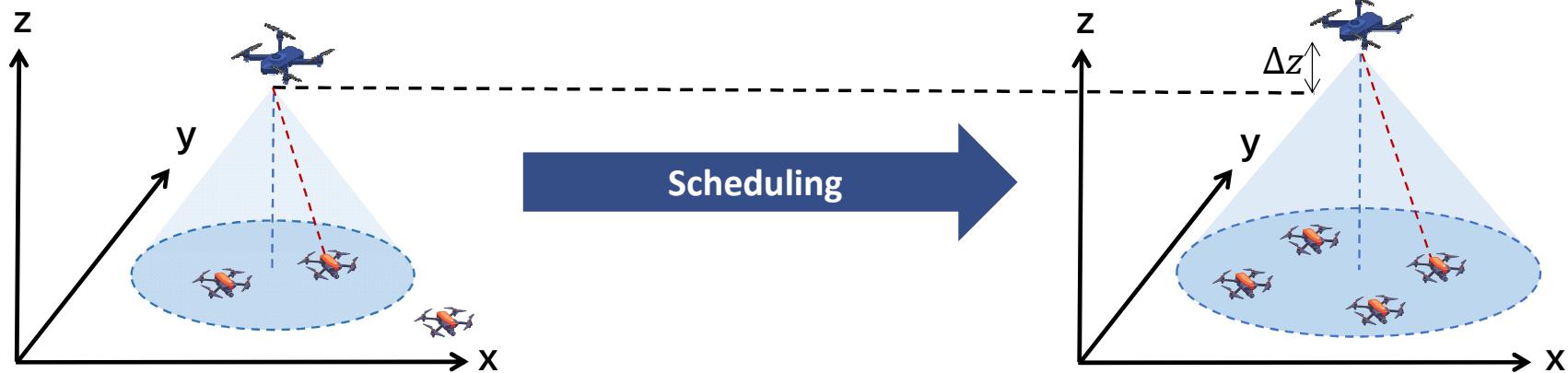
$$0 \leq y_i^t, y_a^t \leq W, t = 0, \dots, T, i = 1, \dots, N$$

$$0 \leq z_a^t \leq H, t = 0, \dots, T$$

Operation area constrain

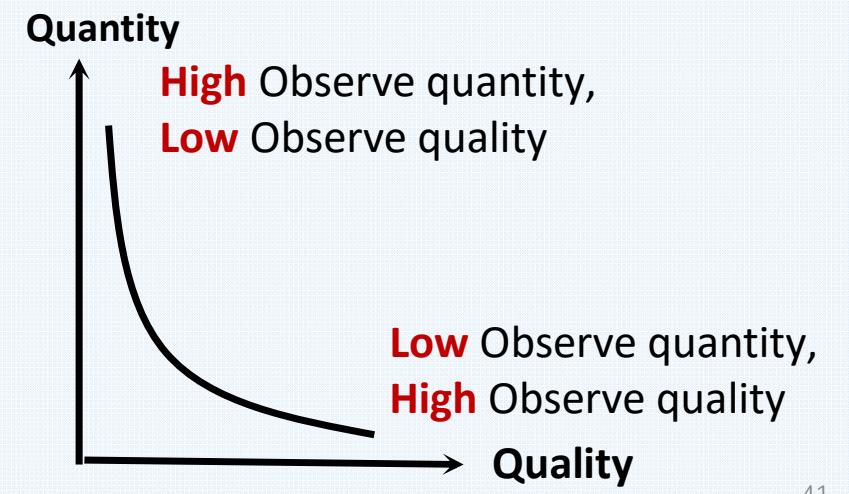
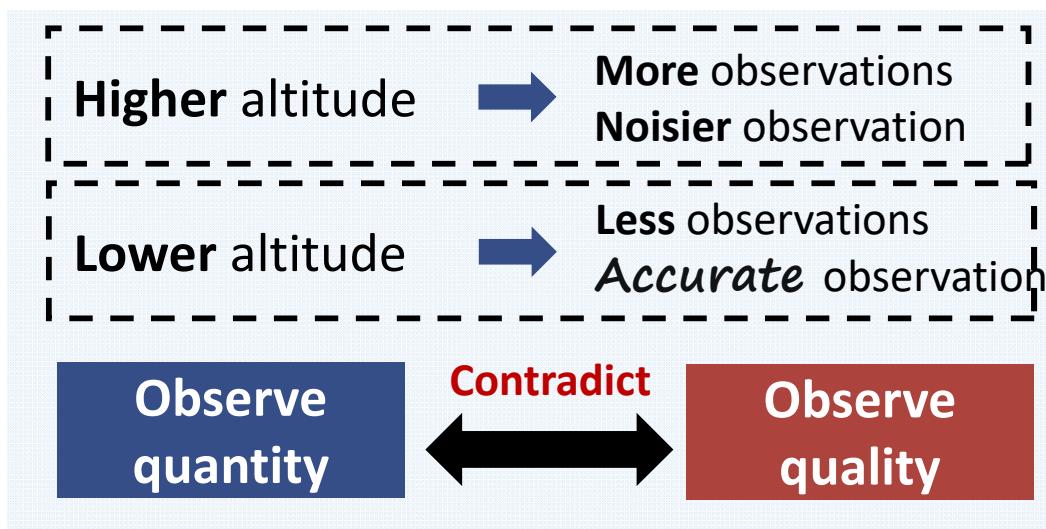
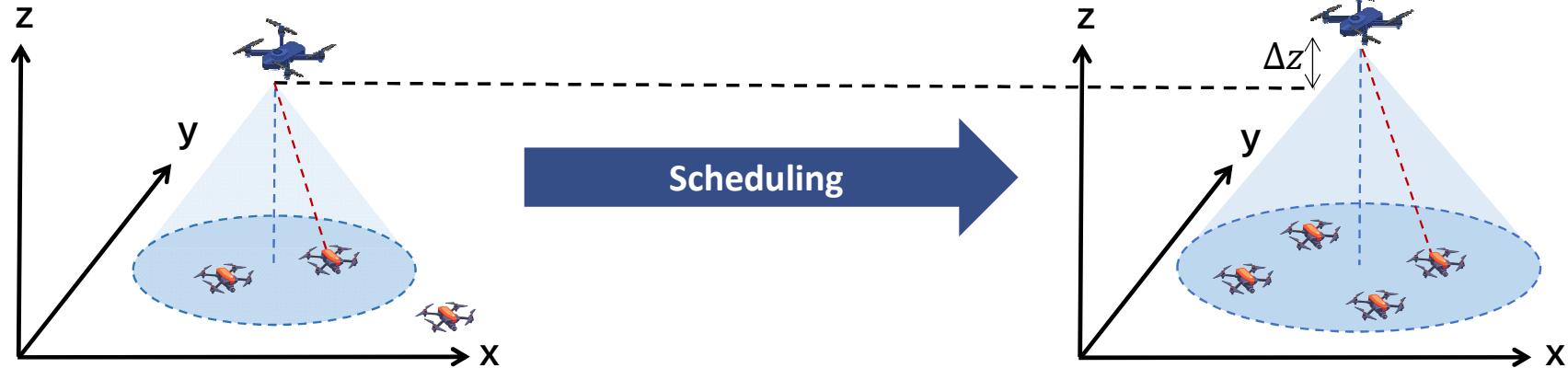
# Challenges of H-SwarmLoc

## ➤ Challenge 1: Inconsistent Goals



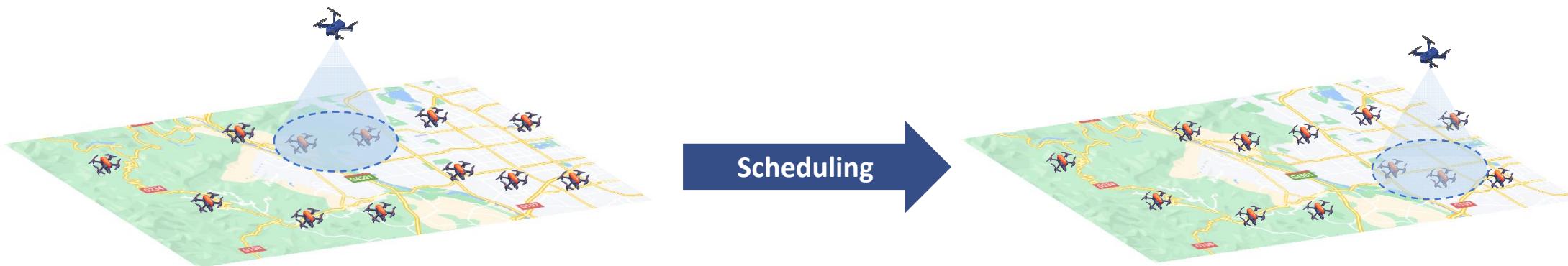
# Challenges of H-SwarmLoc

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# Challenges of H-SwarmLoc

## ➤ Challenge 2: High computational cost



Need to limit the localization error of BMAs for **a long term**

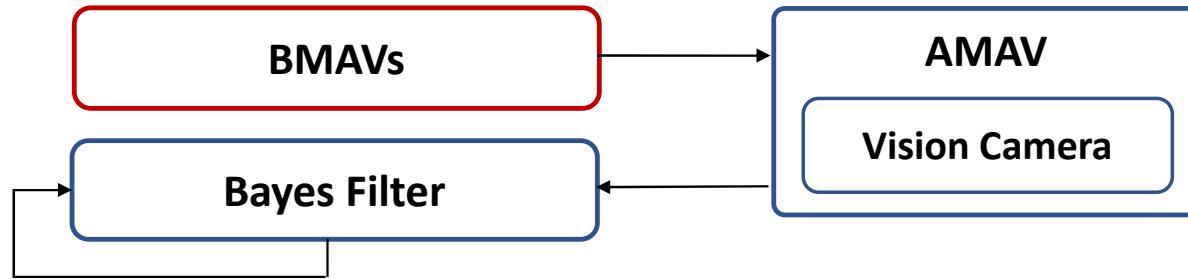


A receding horizon path-planning problem



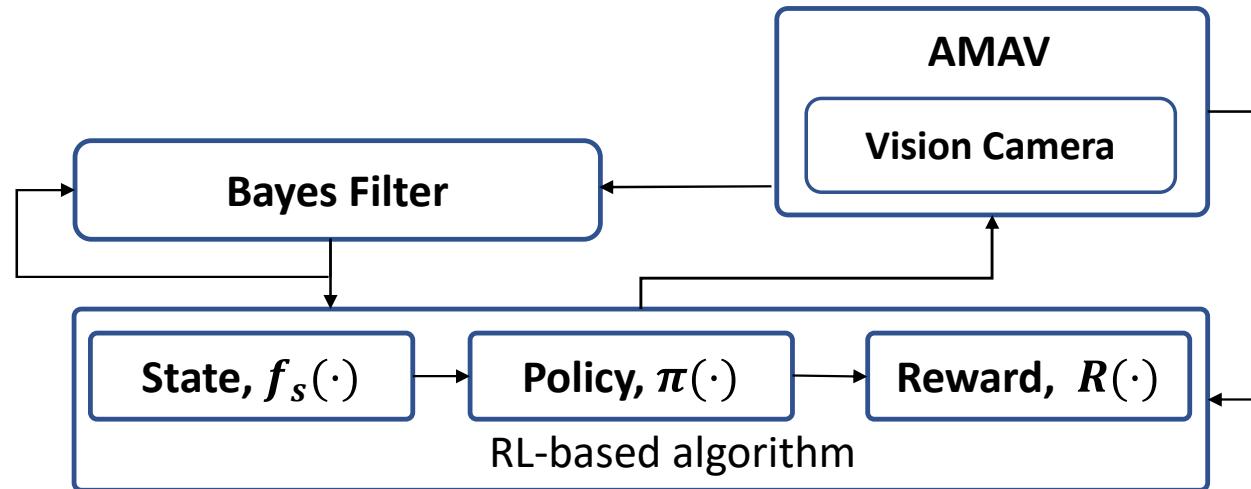
**High computational cost!**

# Decision Diagram of H-SwarmLoc



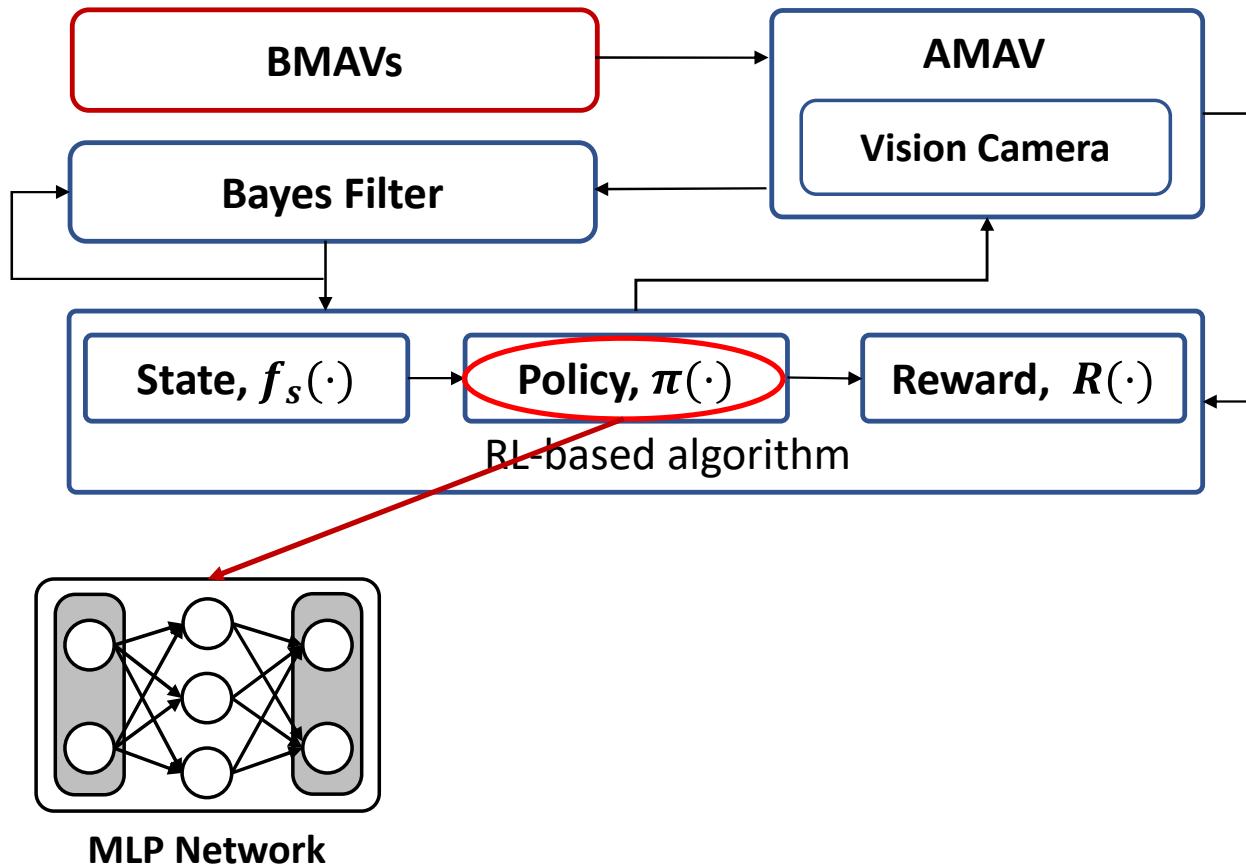
Using **Bayes Filter** to fuse velocity and observation

# Decision Diagram of H-SwarmLoc

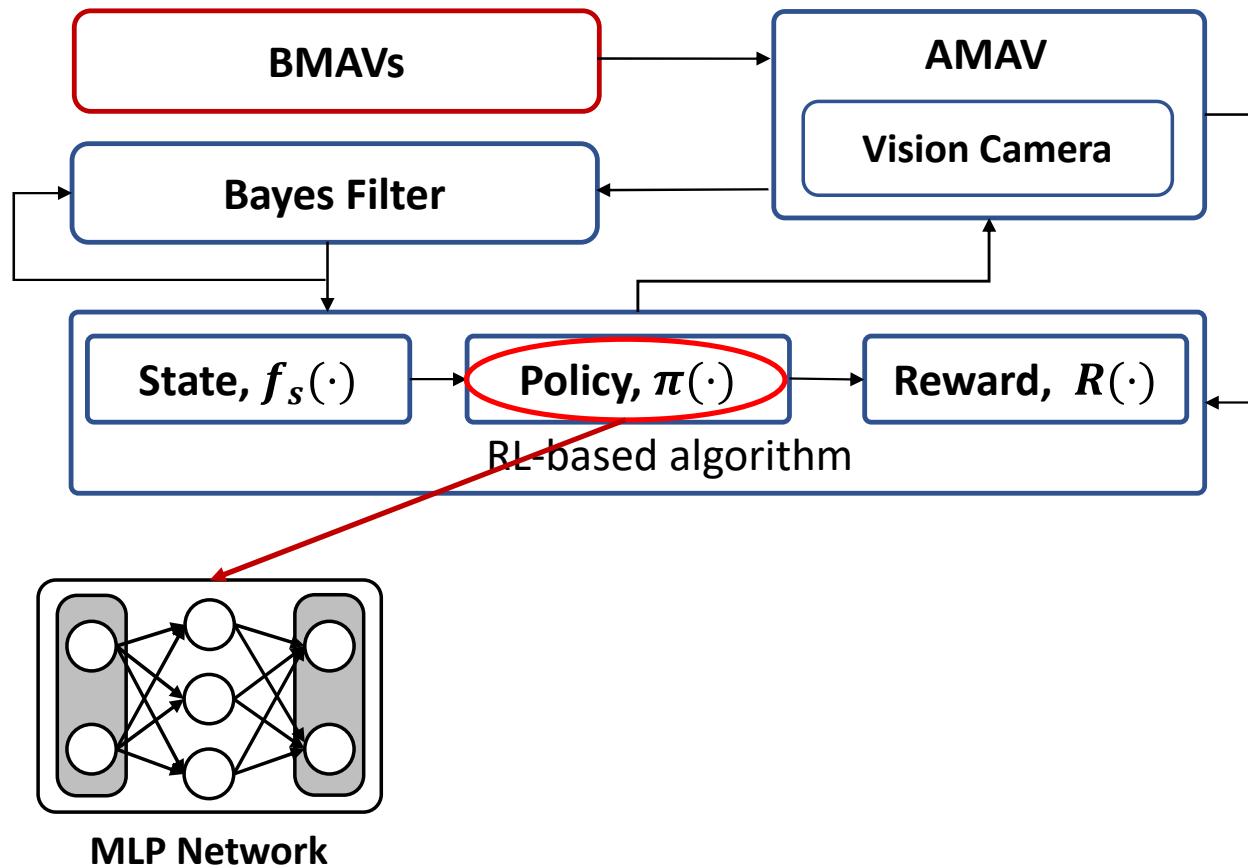


Using **RL-based algorithm** to schedule the movement

# Decision Diagram of H-SwarmLoc

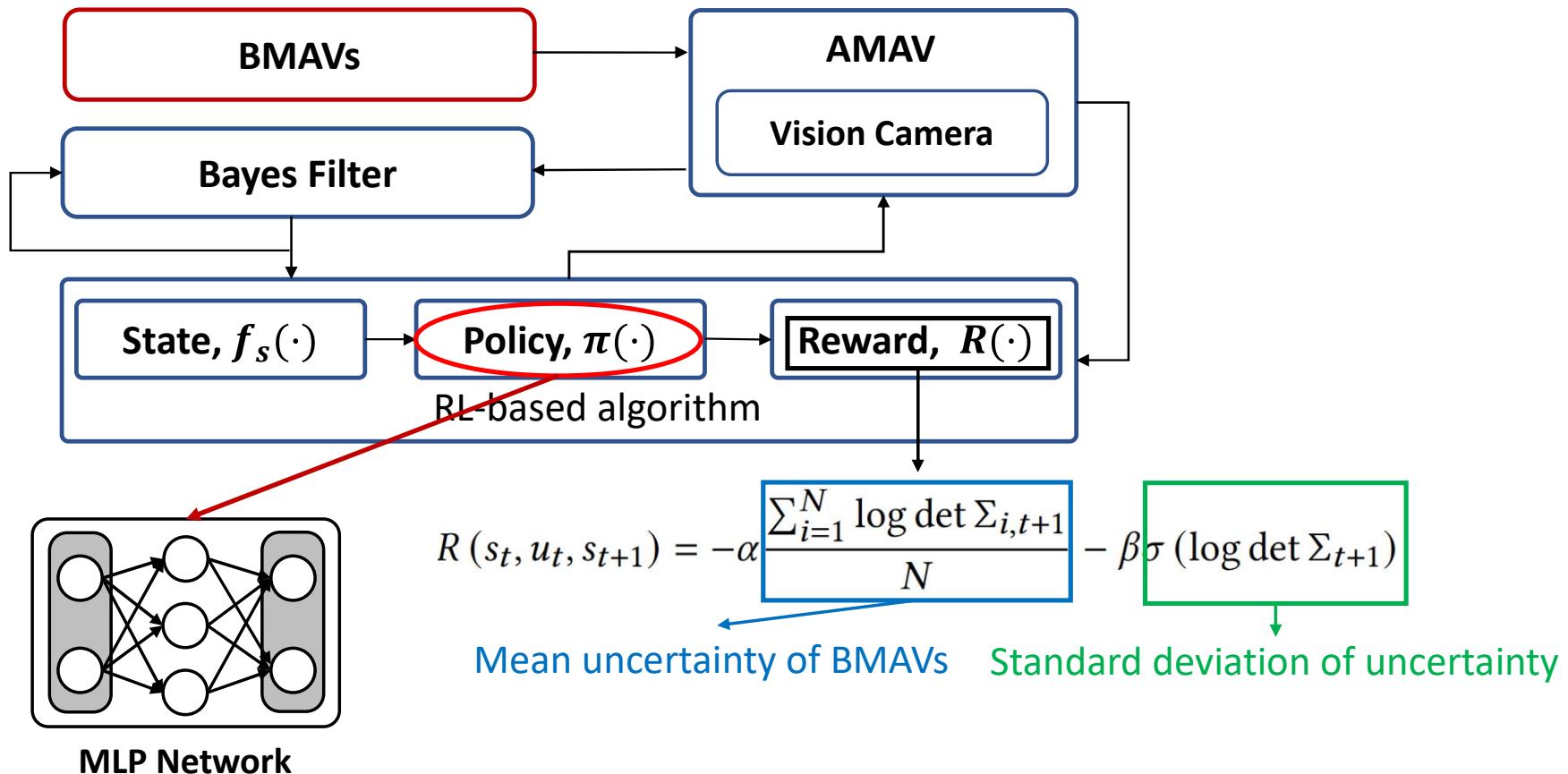


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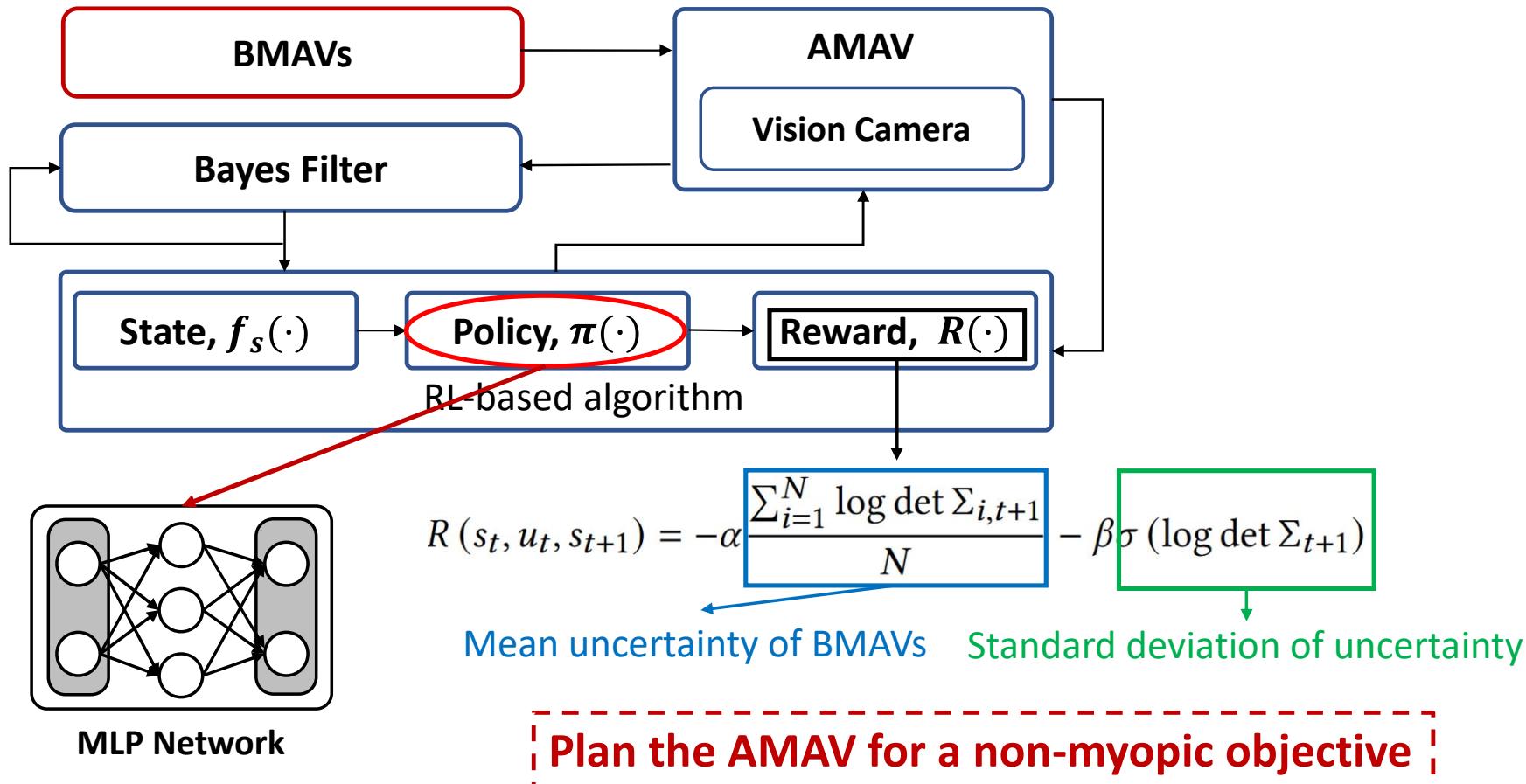


Learn the structural characteristics of estimations

# Decision Diagram of H-SwarmLoc



# Decision Diagram of H-SwarmLoc



# Evaluation Setup

## ➤ The arena and parameters

- The length 100, width 100, and height 40 of simulation scenario are 100, 100, 40

- Three Basic MAVs and one Advanced MAV

## ➤ Estimation model of the BMAV

- Kalman filter is adopted to estimate the state

## ➤ Baselines

- Dead-Reckoning with Map Bias (DR)
  - Random (RA)
  - Greedy (GR)
- Without AMAV*
- The AMAV participates in localization*

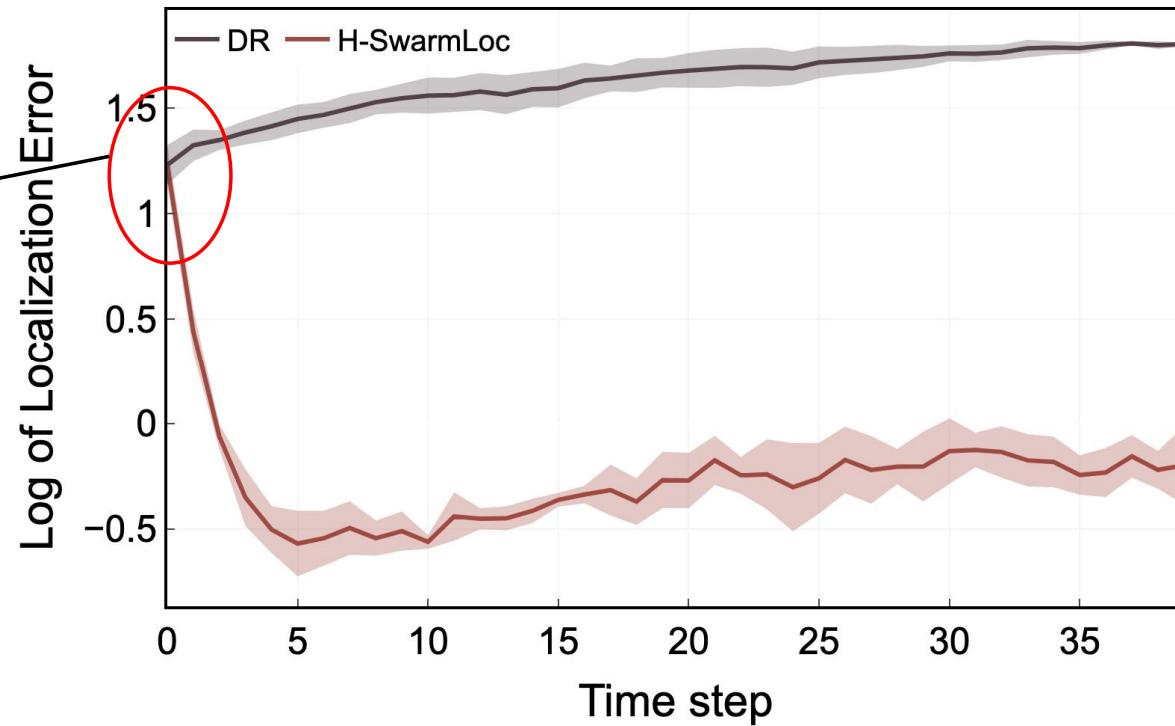
## ➤ Metrics

$$\delta = \frac{\sum_{i=1}^N \|y_i^t - \hat{y}_i^t\|_2}{N}$$

Mean localization error of all BMAVs

# Results: The Introduction of Advanced MAV

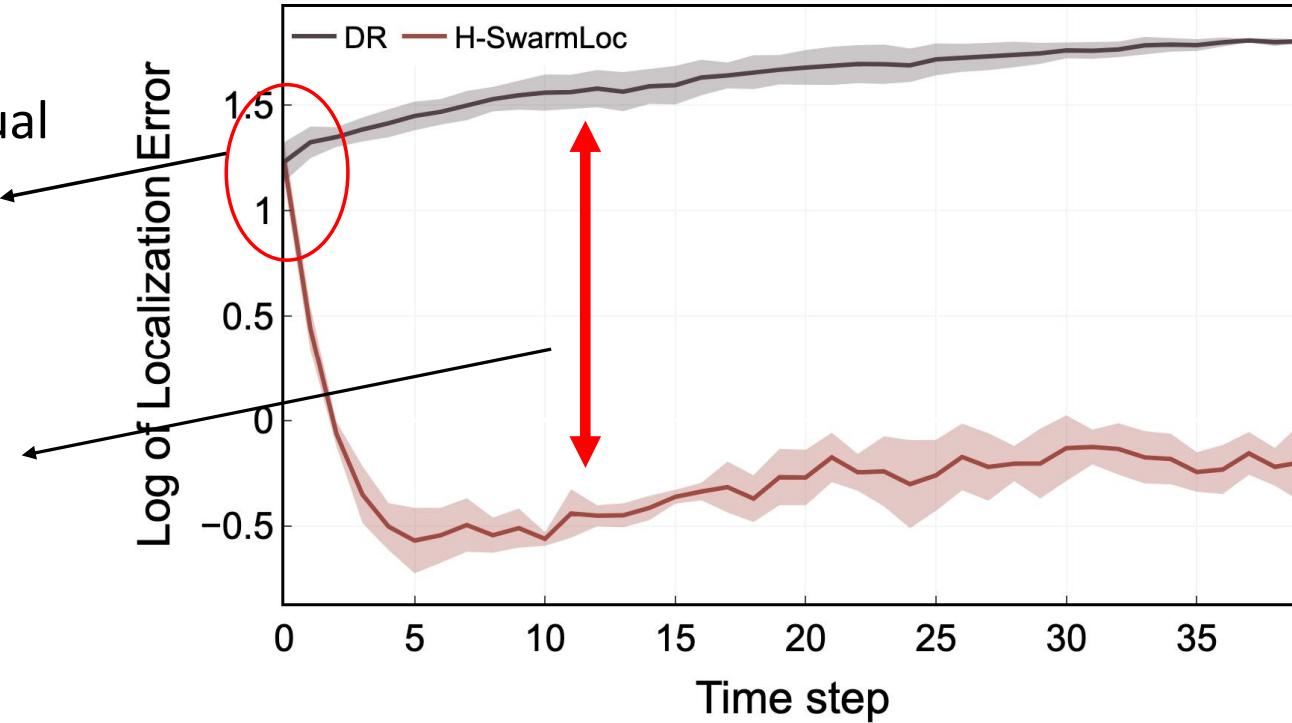
Distance between the actual location and estimation



# Results: The Introduction of Advanced MAV

Distance between the actual location and estimation

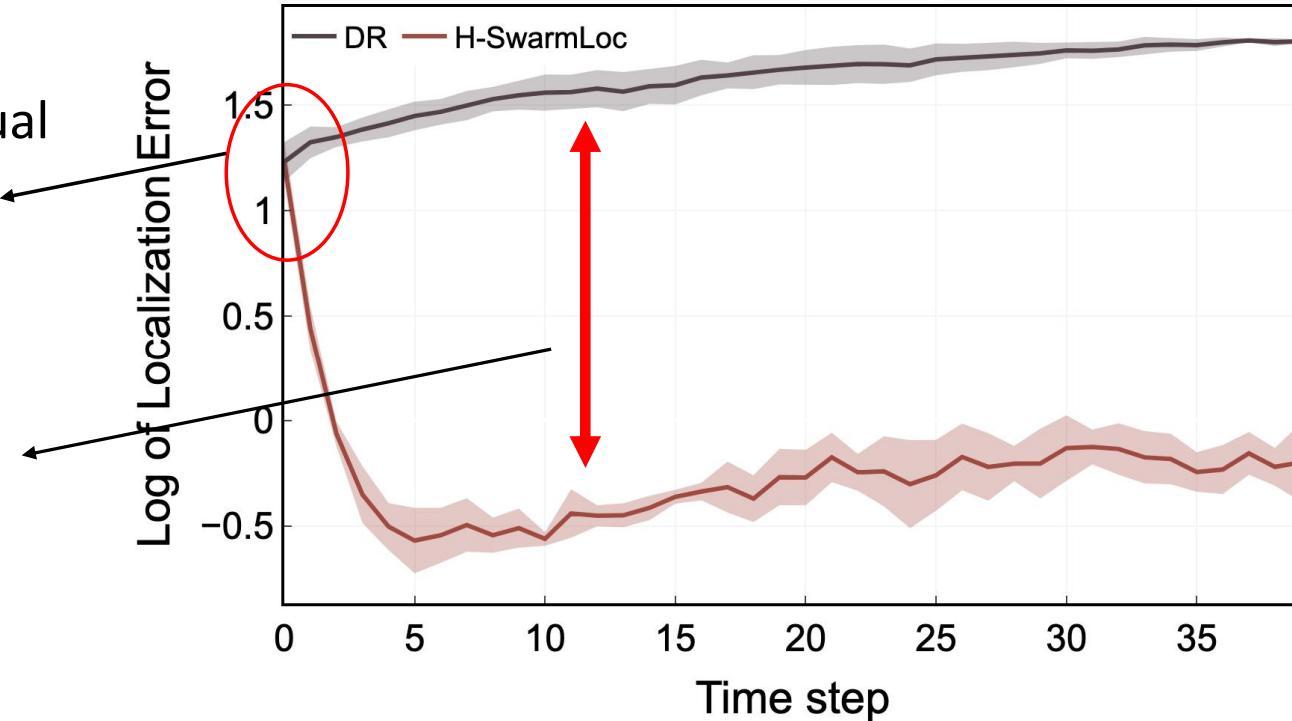
Improvement 78%  
on average



# Results: The Introduction of Advanced MAV

Distance between the actual location and estimation ←

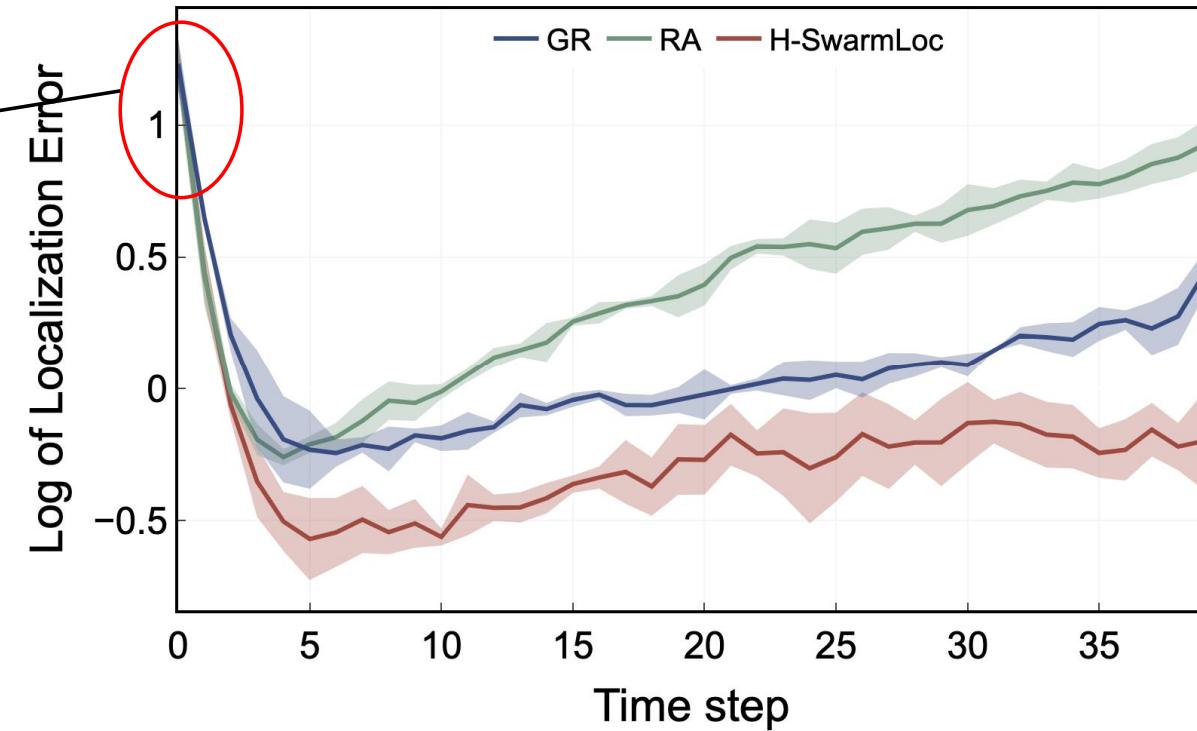
**Improvement 78%**  
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The introduction of the Advanced MAV **improve** the localization performance

# Results: Schedule Algorithm Comparation

Distance between the actual location and estimation

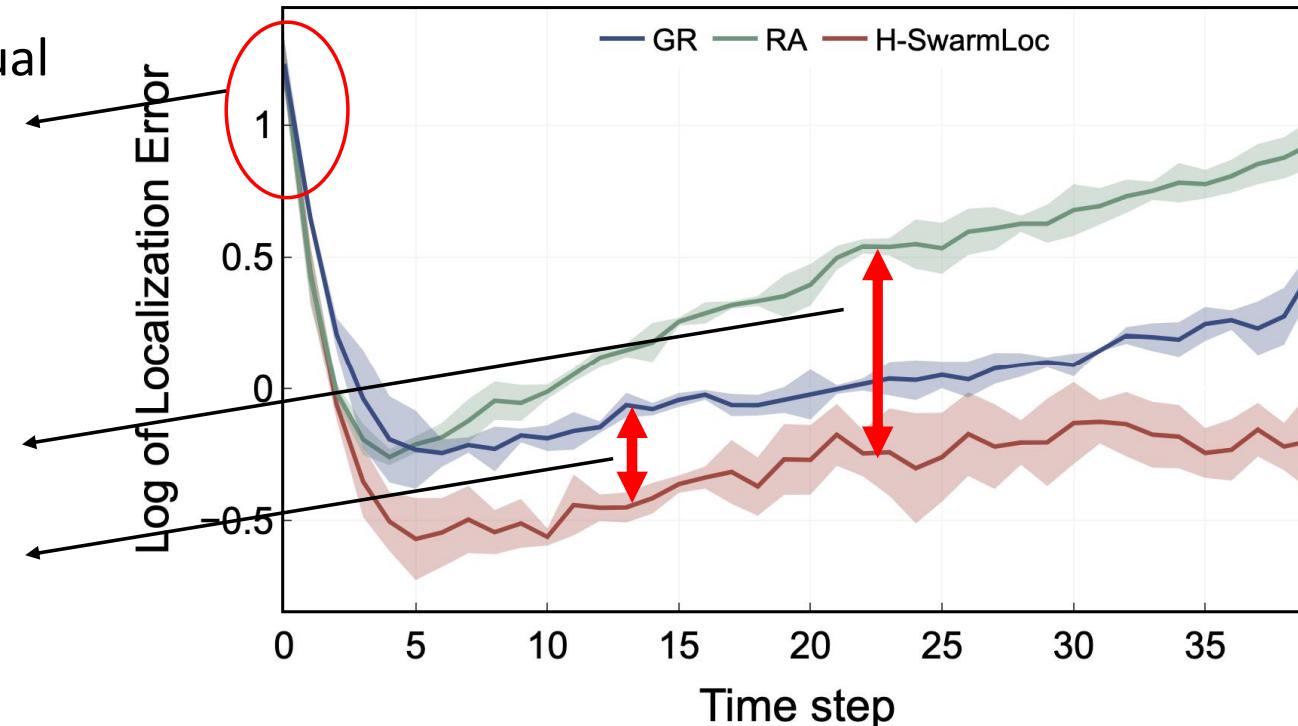


# Results: Schedule Algorithm Comparation

Distance between the actual location and estimation

Improvement 38% on average

Improvement 12% on average

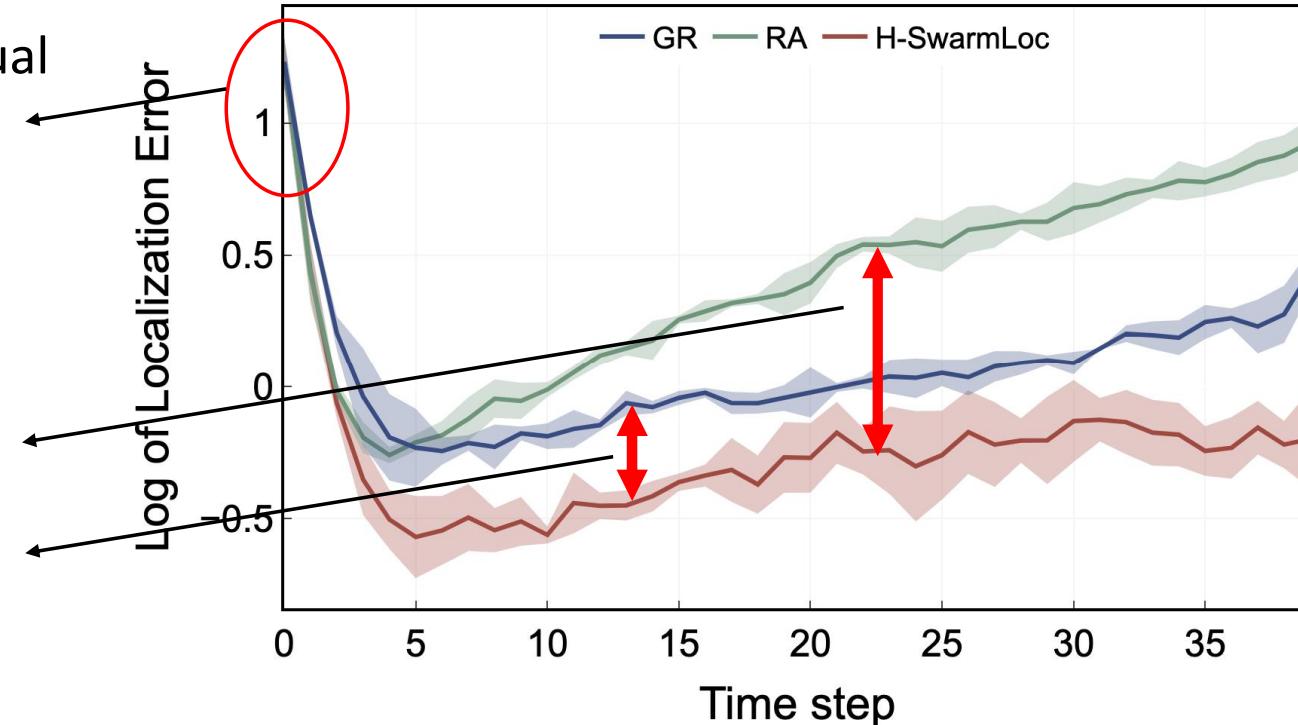


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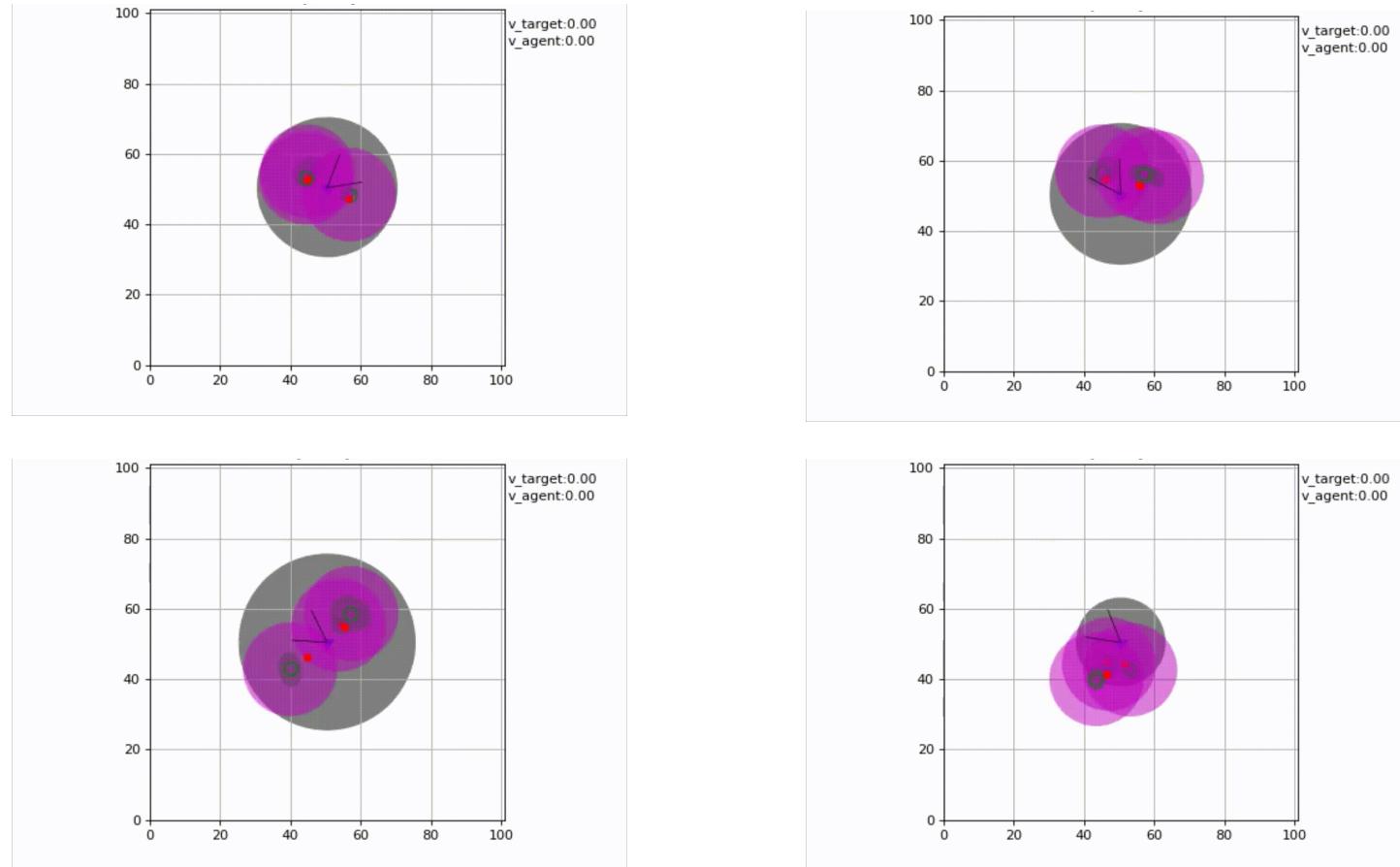
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H-SwarmLoc Plan the motions of the AMAV for the **non-myopic objective**

# Demonstration



AMAV helps localize whole system

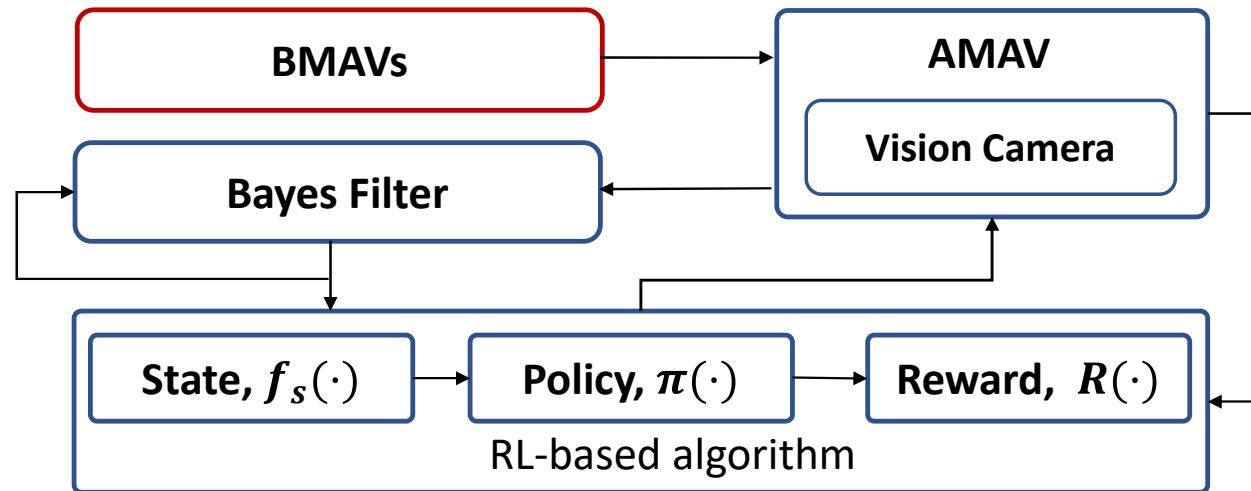
# Summary of H-SwarmLoc

- Propose a system to localize the low-cost heterogeneous MAV swarm accurately.
- Propose H-SwarmLoc, a reinforcement learning-based planning method
- Evaluate the proposed system and method with physical feature-based experiments

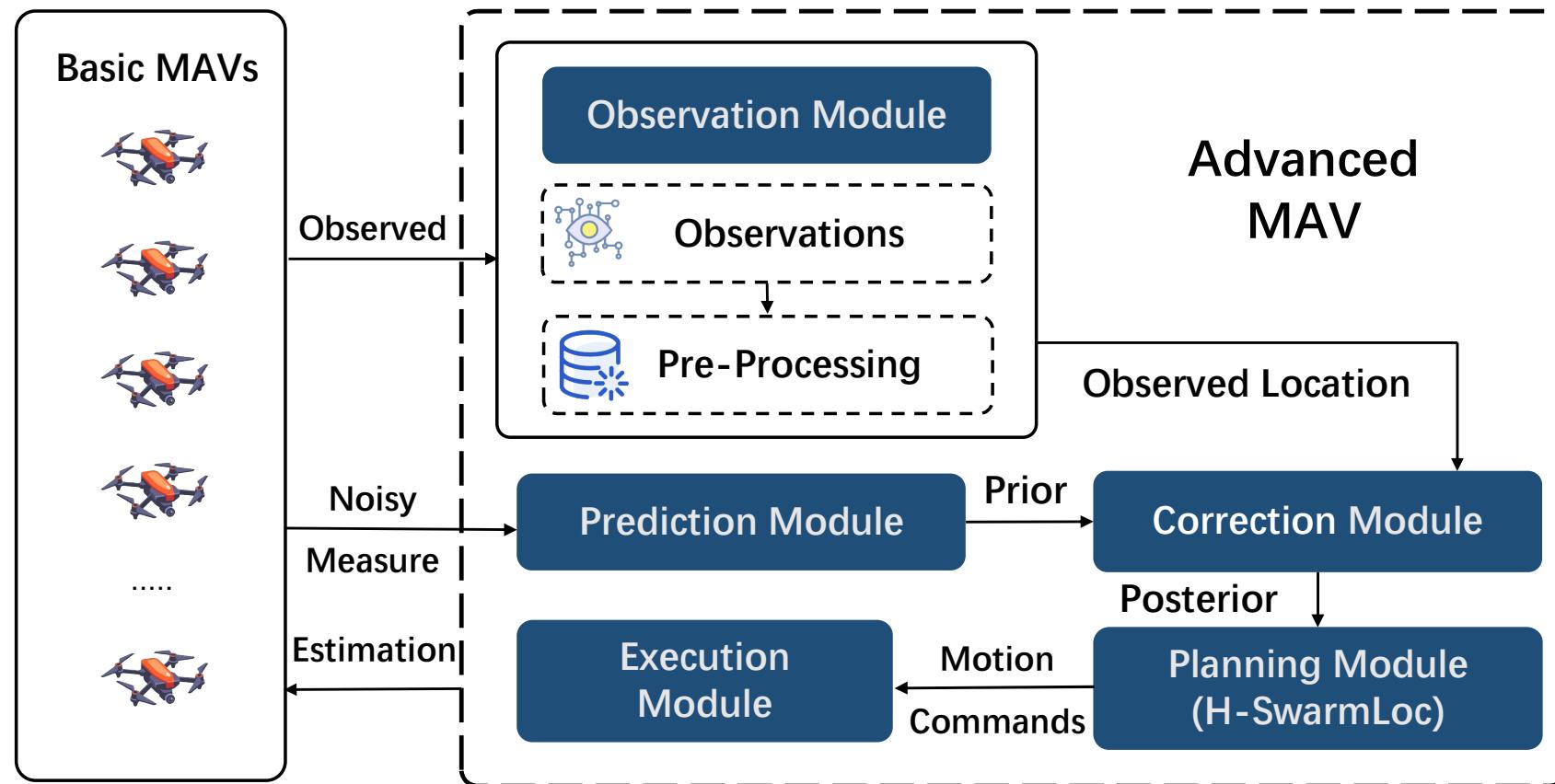
# Thank You! Questions?

Presenter: Haoyang Wang, TBSI  
Email: haoyang-22@mails.tsinghua.edu.cn

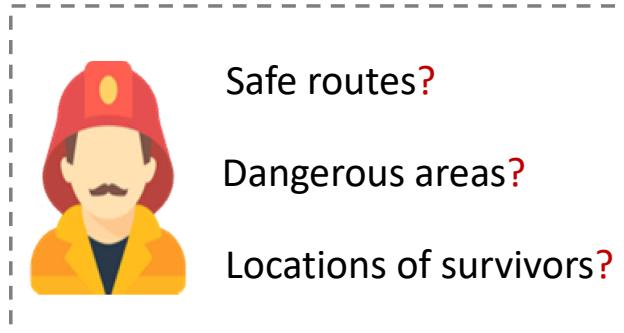
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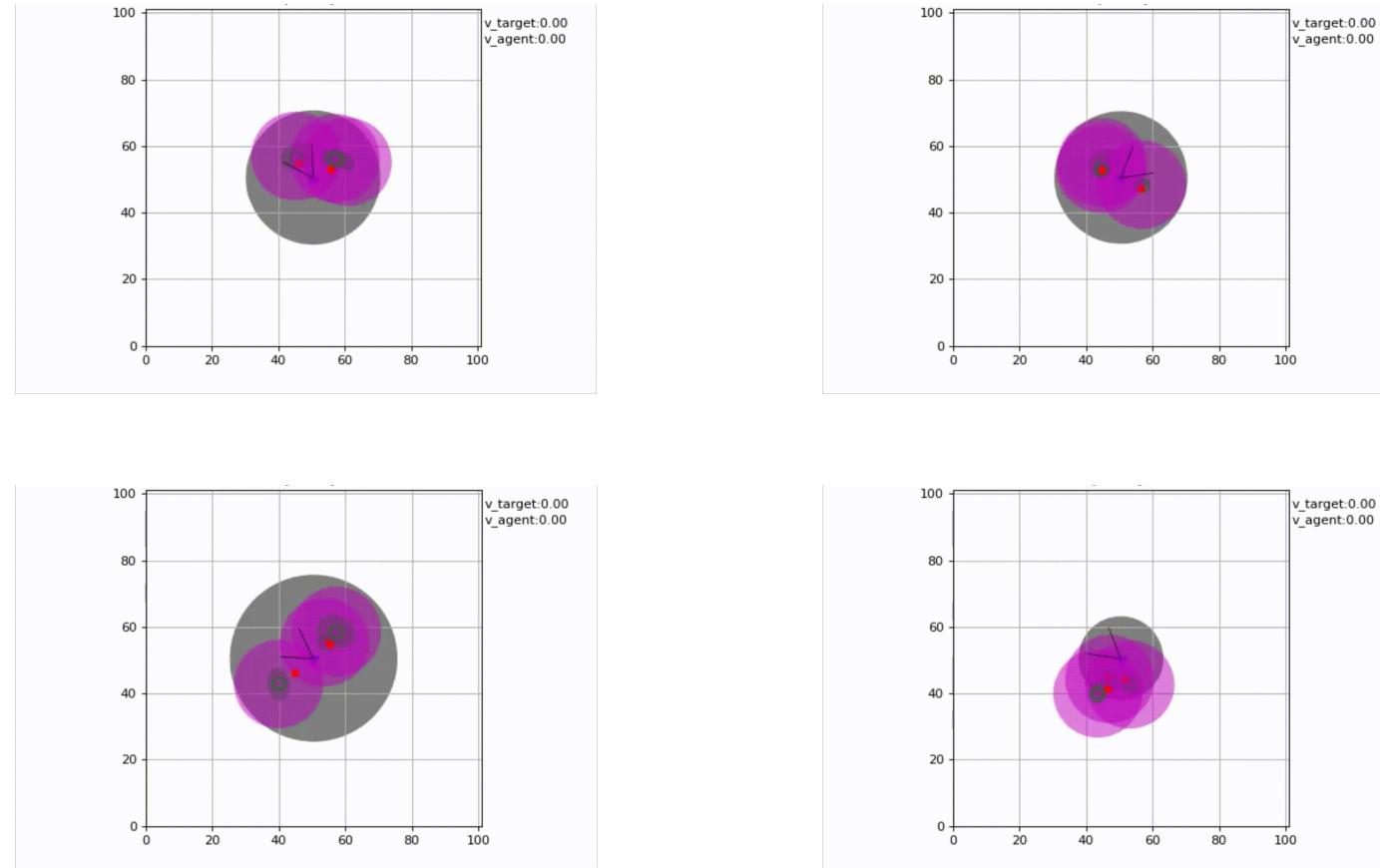
# Our Proposed Drone Swarm System



# Opportunity: Tiny Drone Swarm



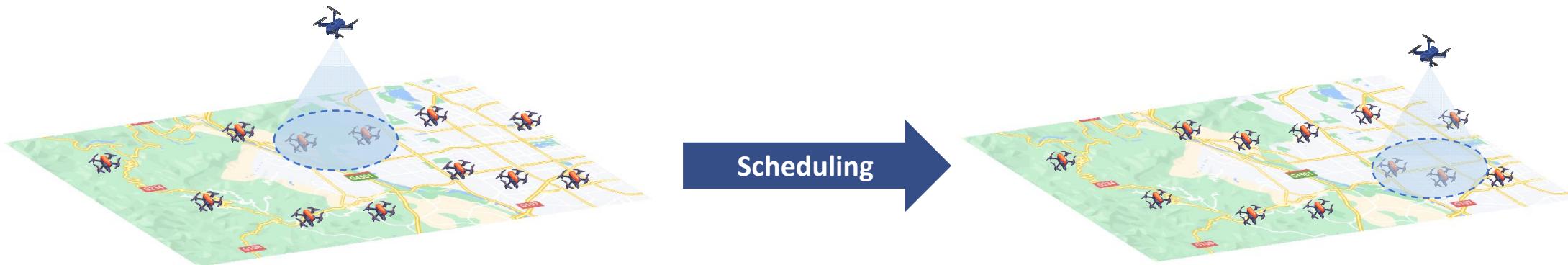
# Demonstration



AMAV helps localize whole system

# Challenges of H-SwarmLoc

## ➤ Challenge 2: High computational cost



Need to limit the localization error of BMAs for **a long term**

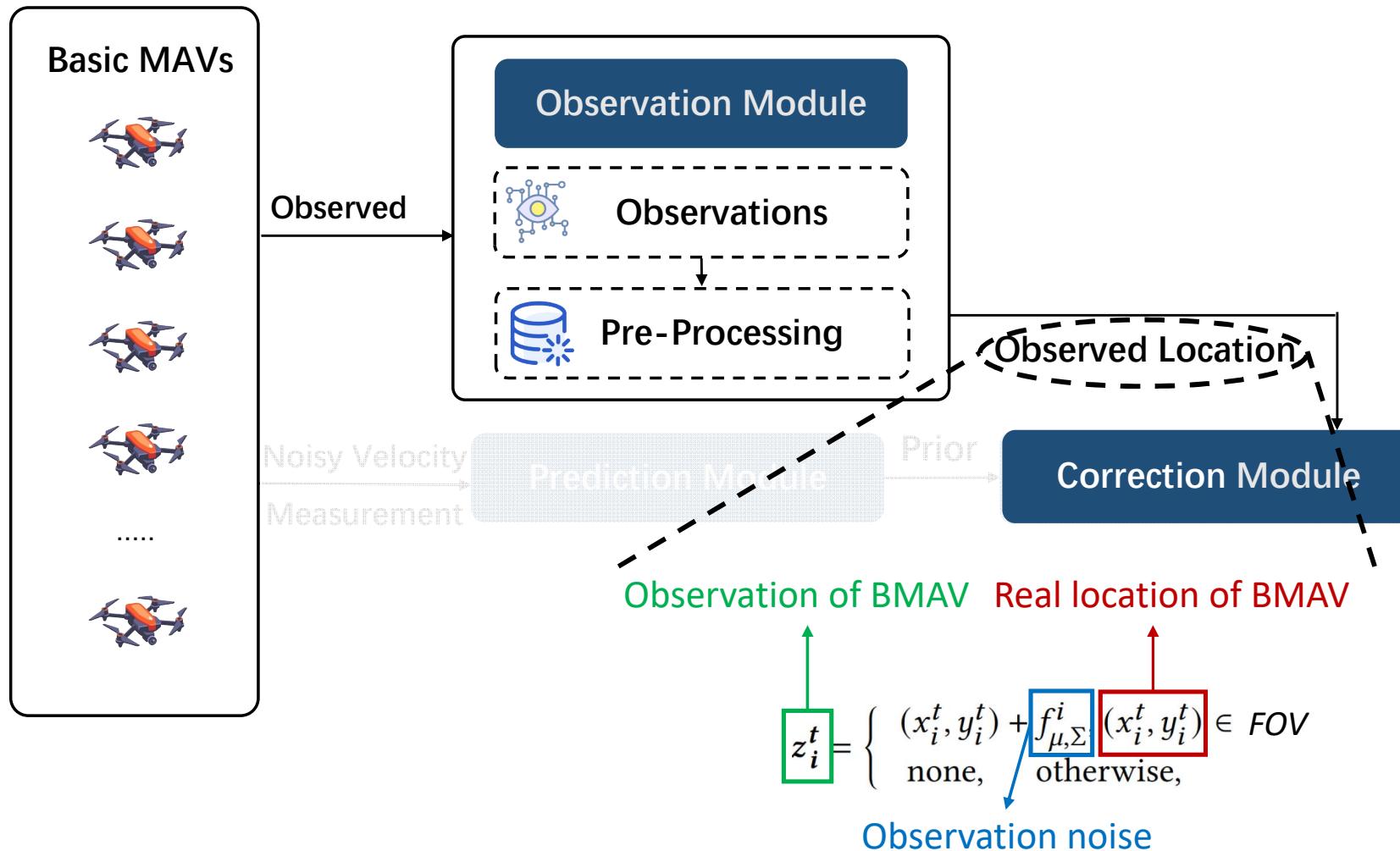


A receding horizon path-planning problem



**High computational cost!**

# Our Proposed Drone Swarm System

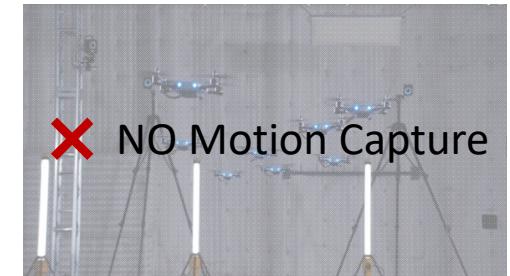


# The Research Objective

➤ Low-cost Drone Swarm

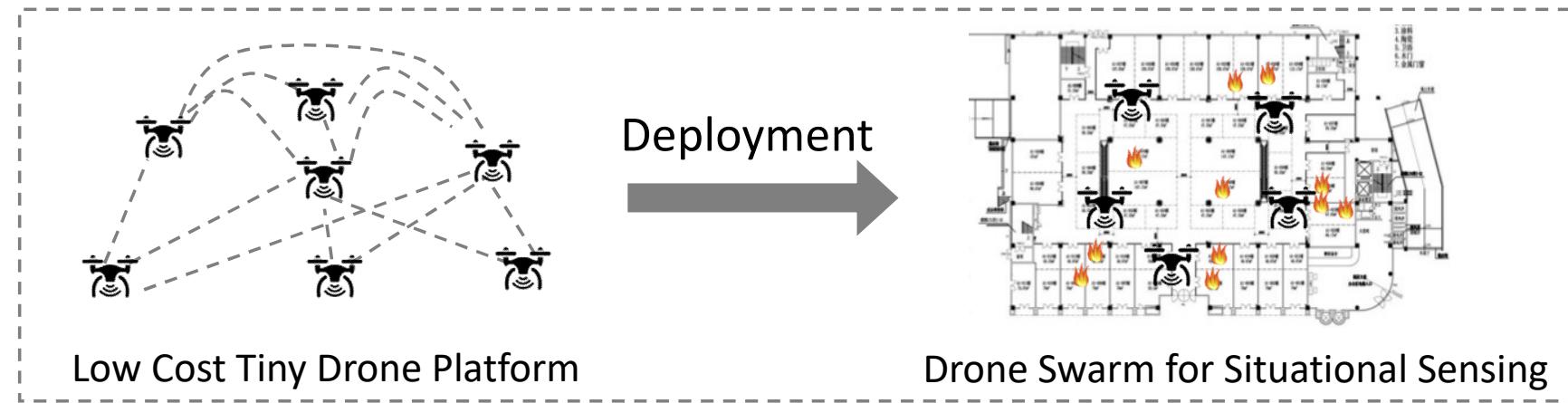


➤ No Extra Localization Infrastructure



Few Depth cameras

Accomplish precise localization



# Our Proposed Drone Swarm System

