MicNest: Long-Range Instant Acoustic Localization of Drones in Precise Landing

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Flying Meals

Main Procedures of Drone Delivery

1. Online Order

2. Package

3. Take off

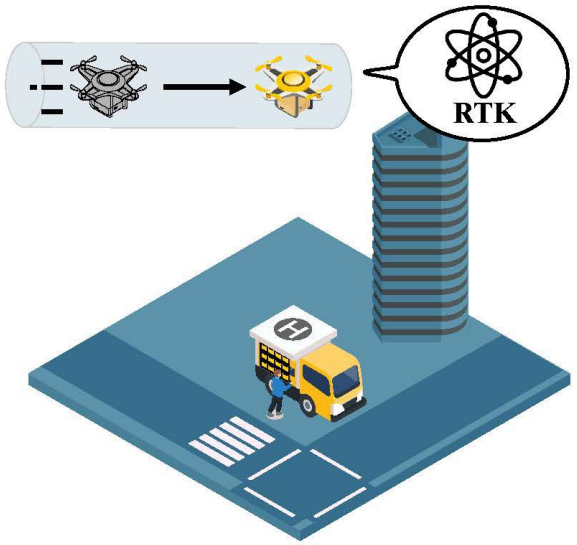
4. Fly to the destination

5. Land and dock onto the self-collection station

6. Fetch

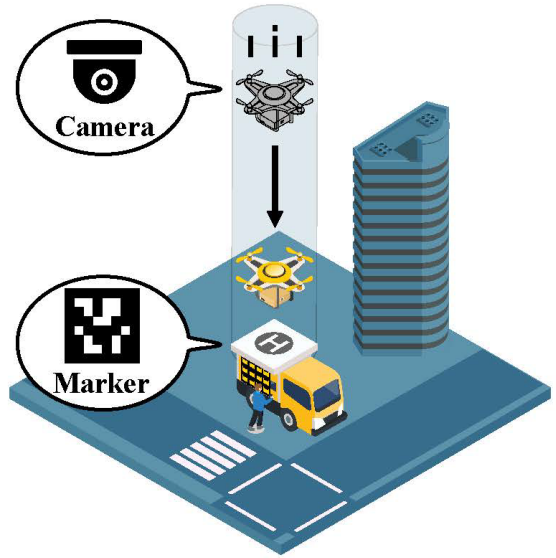
State-of-the-Art in Precise Landing

Step 1: Horizontal approach



- ✓ High Precision
- ✓ Vast Coverage
- ✗ Unstable Performance

Step 2: Vertical descent

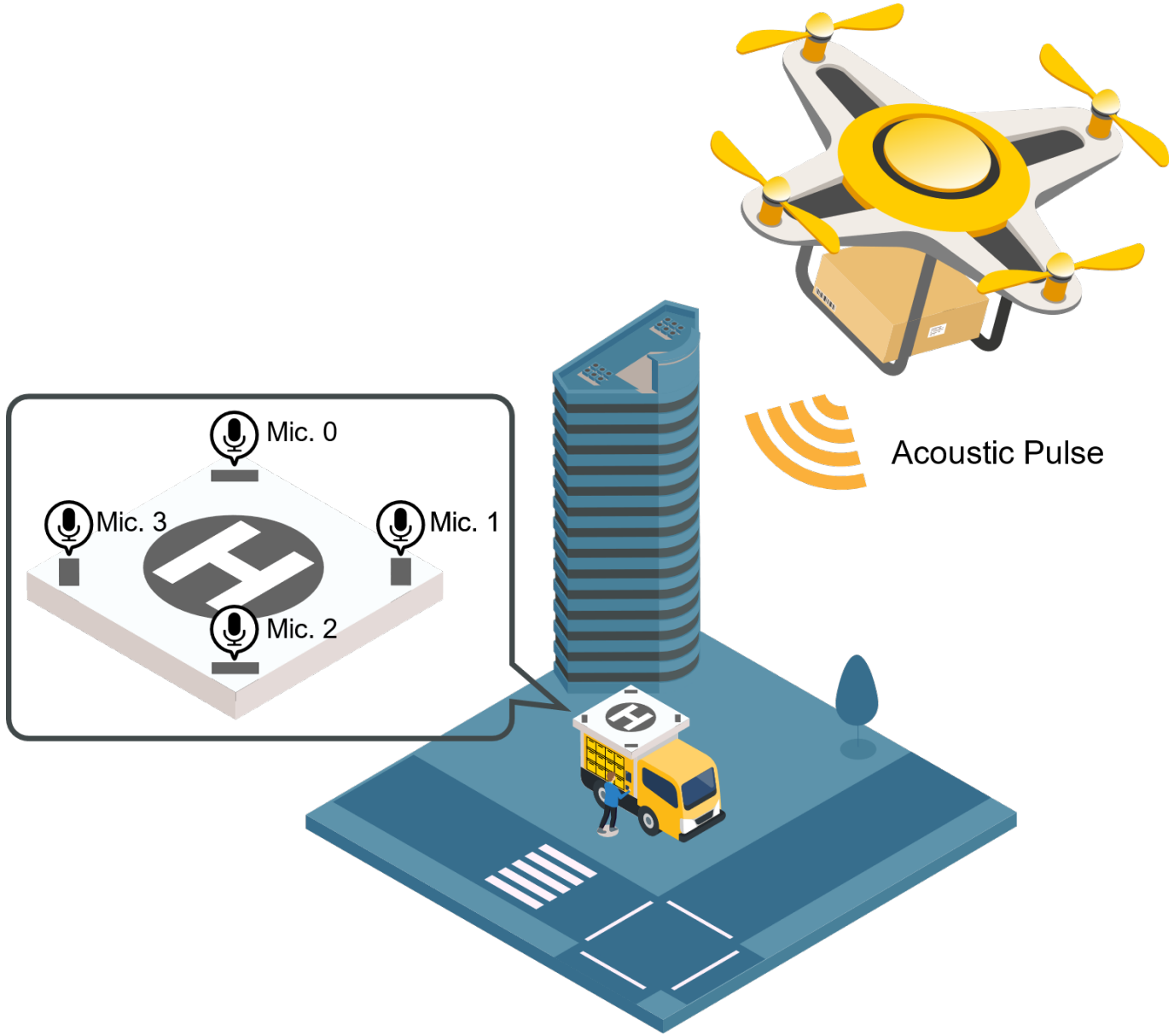


- ✓ High Precision
- ✗ Limited Coverage
- ✗ Sensitive to lighting conditions

Problem: Exiting SOTA techniques can not provide reliable localization services for precise landing.

MicNest:

Acoustic Localization System for Drone Landing

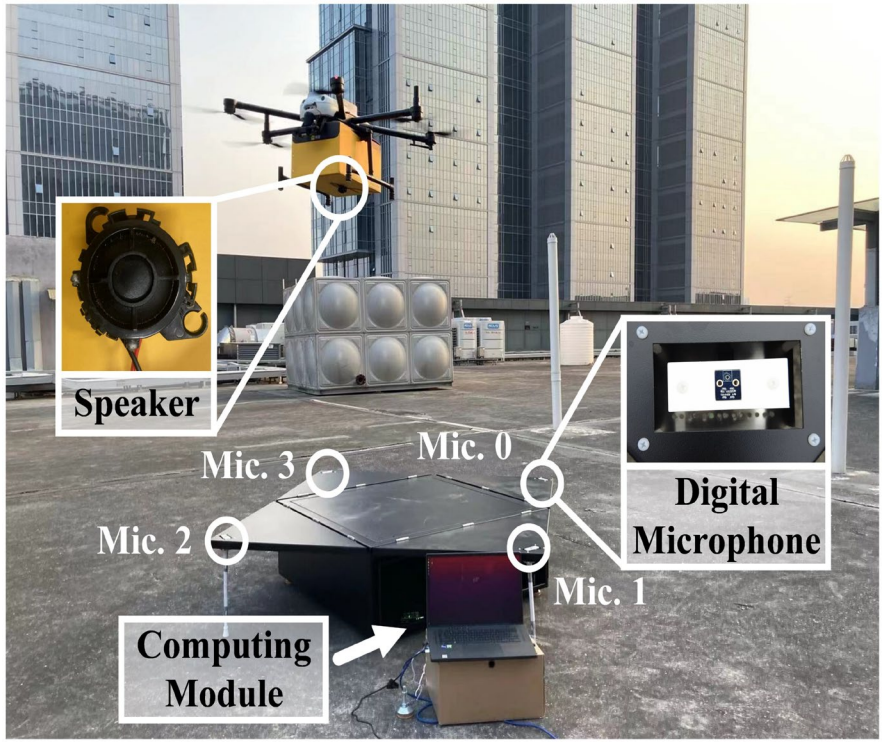


120 m
Operation Range

0.53%
Relative Localization Error

20 Hz
Location Update Rate

MicNest in a Nutshell



Hardware

Pulse Transmission

The pulse transmitted by each drone:

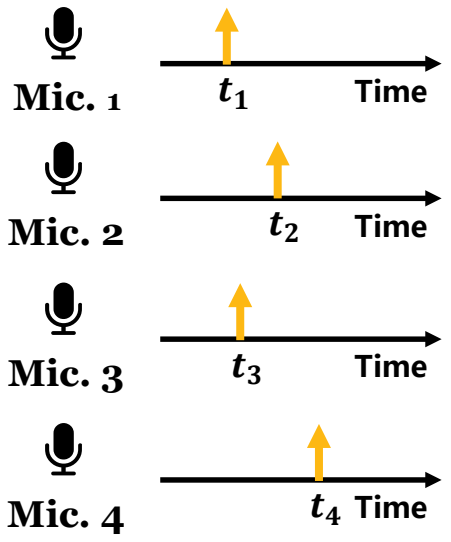
$$\boldsymbol{s} = [s_0, s_1, \ldots, s_n, \ldots, s_{N-1}]^T$$

Each code s_n is an independent random gaussian variable

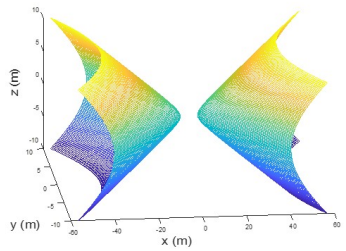
Advantages:

1. Comfortable to hear
2. Concurrent Localization of multiple drones (CDMA)
3. Resistance to spoofing attack

Pulse Detection



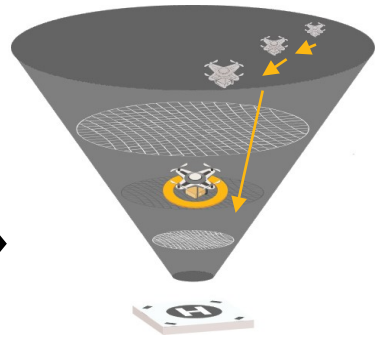
Hyperboloids



$$abs(|PM_1| - |PM_3|) = 2a_1$$

$$abs(|PM_2| - |PM_4|) = 2a_2$$

Localization



By exploiting the onboard altitude sensors, the drone can thus be localized.

Workflow

Why Acoustics?

Spatial Resolution

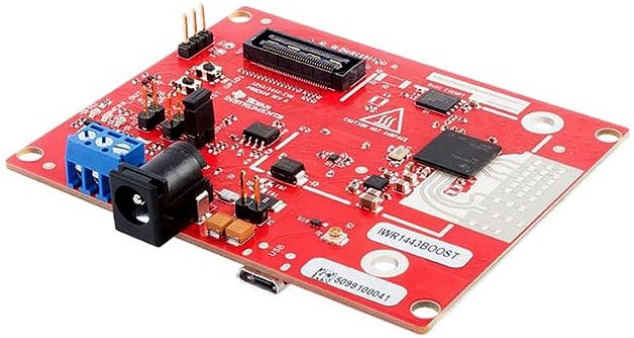
- The **spatial resolution *R*** (absolute ranging resolution) of wireless signal is propotinal to **signal speed *c*** , and is inversely proportional to **signal bandwidth *B***:

$$R \propto \frac{c}{B}$$

- Due to **low sound speed**, the acoustic signal can provide pretty promising spatial resolution.

UWB: Decawave DWM1000

- Bandwidth: 500 MHz – 1 GHz
- Spatial Resolution: **>10 cm**



FMCW: TI IWR1443

- Bandwidth: 500 MHz – 4 GHz
- Spatial Resolution: **>3.75 cm**

Acoustics

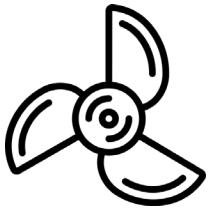
- Bandwidth: 24 KHz
- Spatial Resolution: **0.7 cm**

Challenges

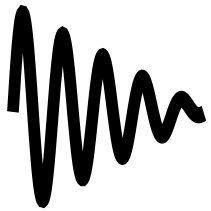
Low SNR

Limited
Tx Power

High
Noise Floor



Strong
Interference



Serious
Attenuation

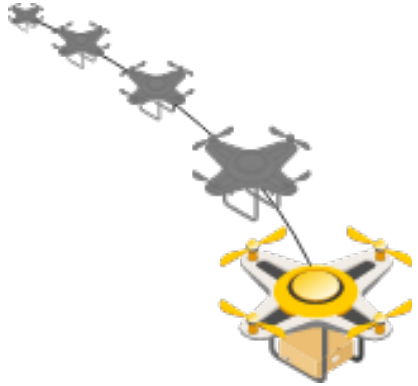
Non-linear Distortion

- Low sound speed leads to significant Doppler distortion.

$$\mu \propto \frac{v}{c}$$

- The flight control loops rapidly change the drone velocity, resulting in non-linear distortions.

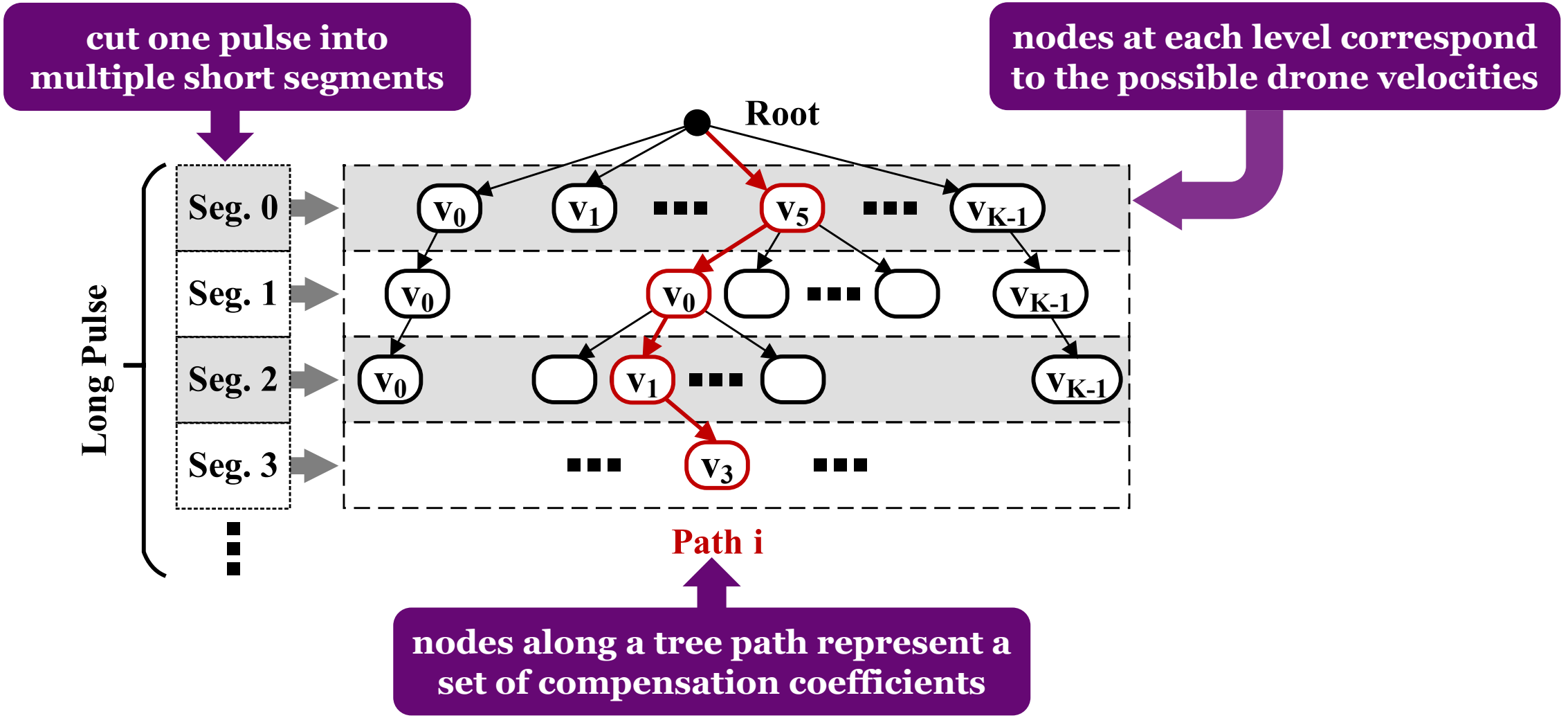
Low Latency



- MicNest is used to navigate moving drones.
- Signal processing must withstand the latency constraint imposed by the nature of flight control loops.

How to detect **low-SNR** pulses with **non-linear distortion efficiently**

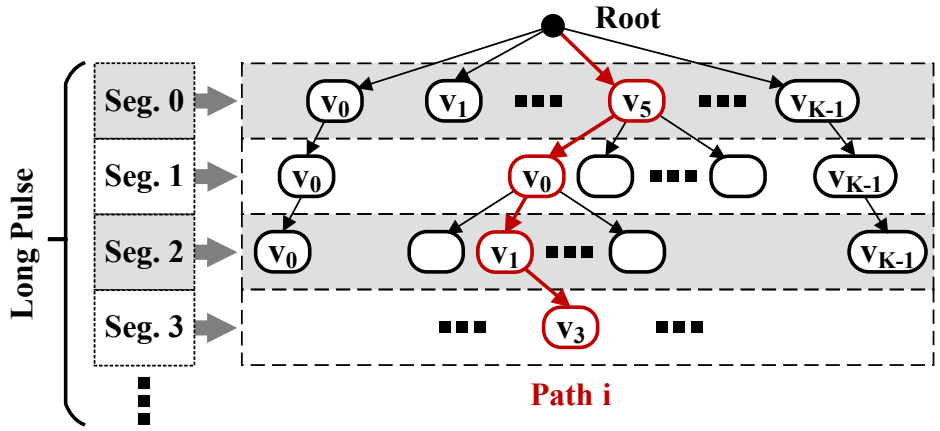
Matched Filter Tree (MFT)



Key Idea: convert pulse detection to a tree search problem

Matched Filter Tree (MFT)

Goal: search for the tree path that can minimize the non-linear distortion



Exhaustive Search

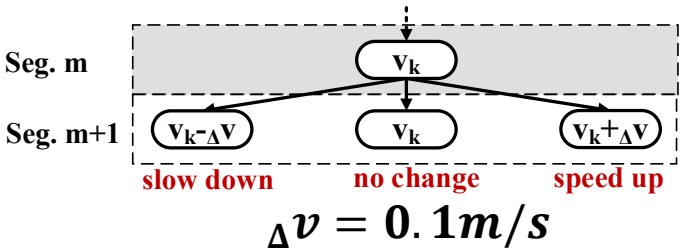
- For each tree path, perform the following operations:
  1. **Compensate** segments by using coefficients
  2. **Concatenate** compensated segments into a new pulse template
  3. **Correlate** the new template with the received signal.
- After visiting all paths, select the tree path with the maximum correlation value;

- The search space grows **exponentially** with #segments
- Each path involves an **expensive** correlation operation

Accelerate Tree Search

Tree Pruning

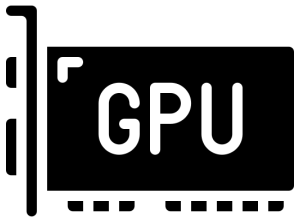
- The drone velocity does not change abruptly
- The branching factor of the tree can be **reduce to 3**



reduce search space

Correlation Acceleration

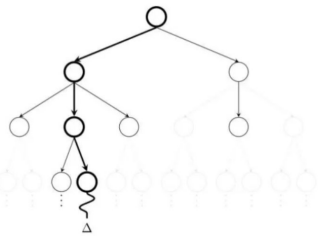
- The pulse-audio correlation can be decomposed into multiple segment-audio correlations.
- This computing scheme (**vector adding**) can be highly parallelized by GPU.



reduce time cost of search path

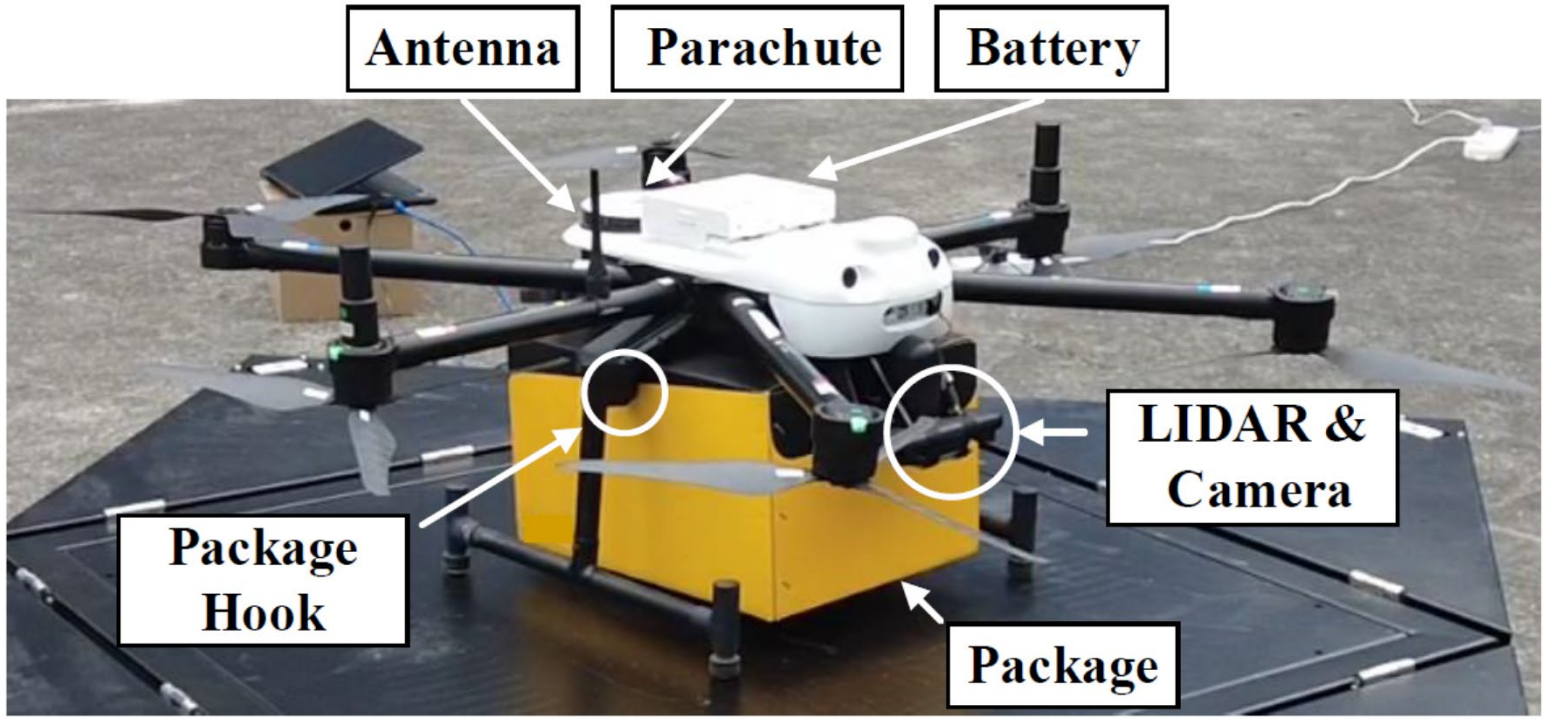
Heuristic Search

- This idea is similar to **Monte-Carlo Tree Search (MCTS)**
- We can exploit visiting history to quickly dive towards the solution.



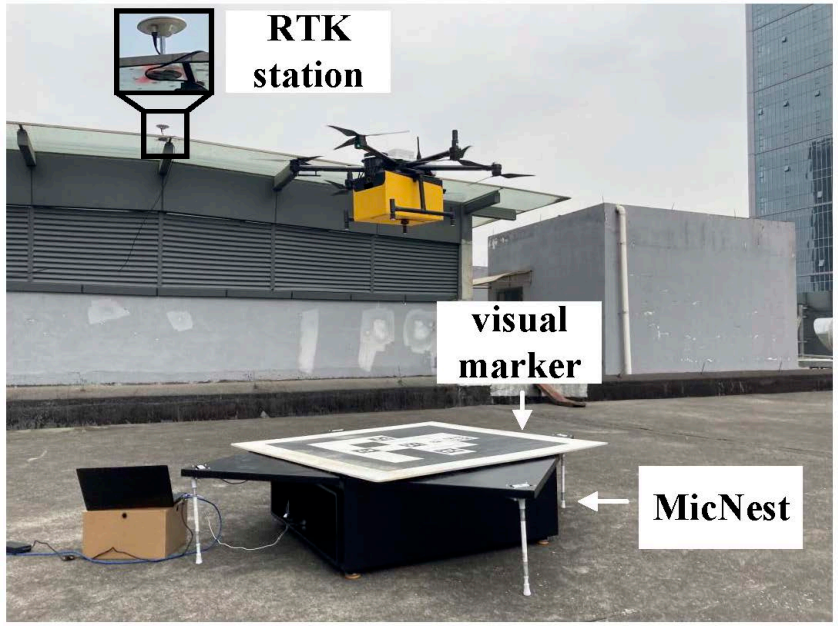
reduce total visit count

Delivery Drone



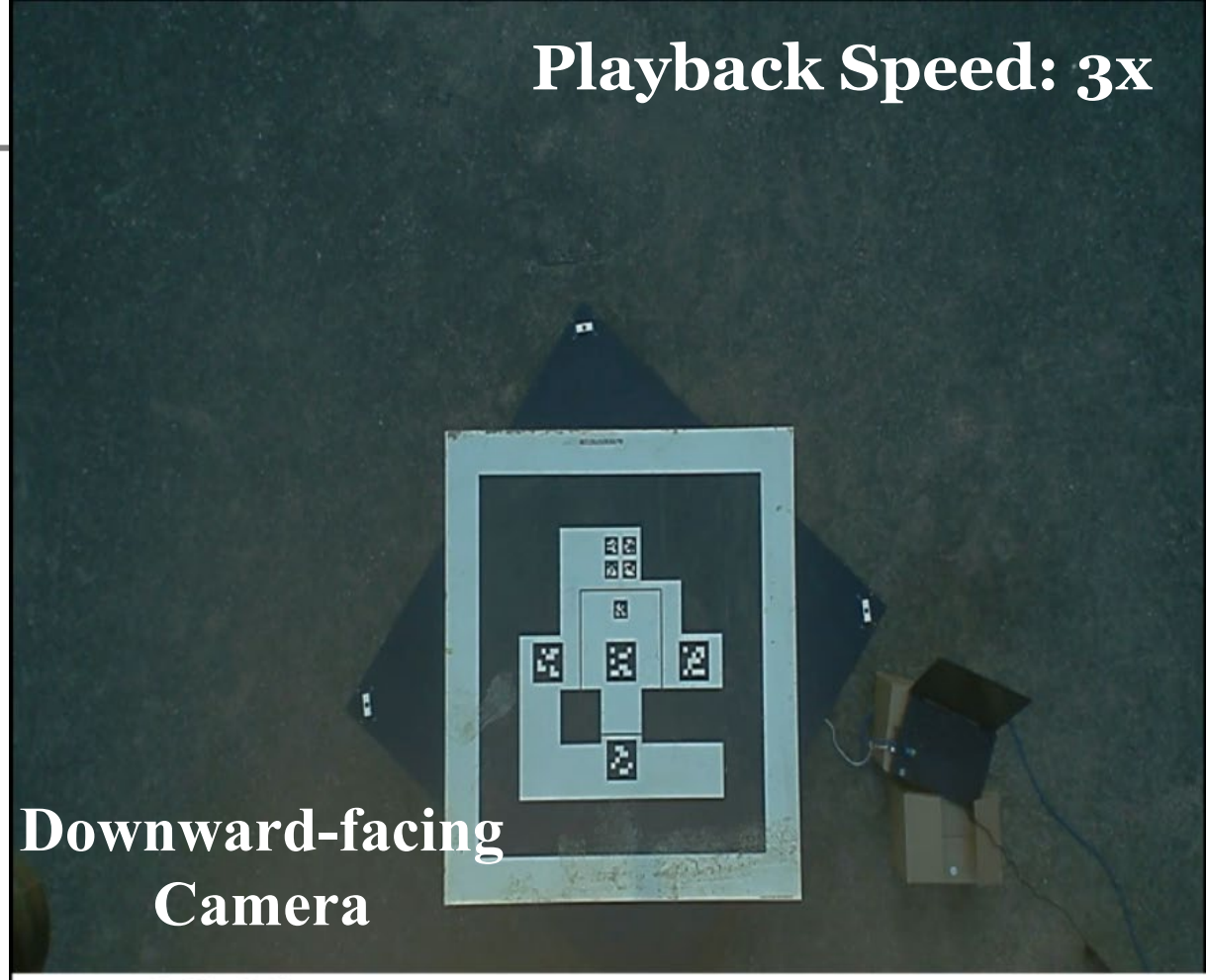
Meituan

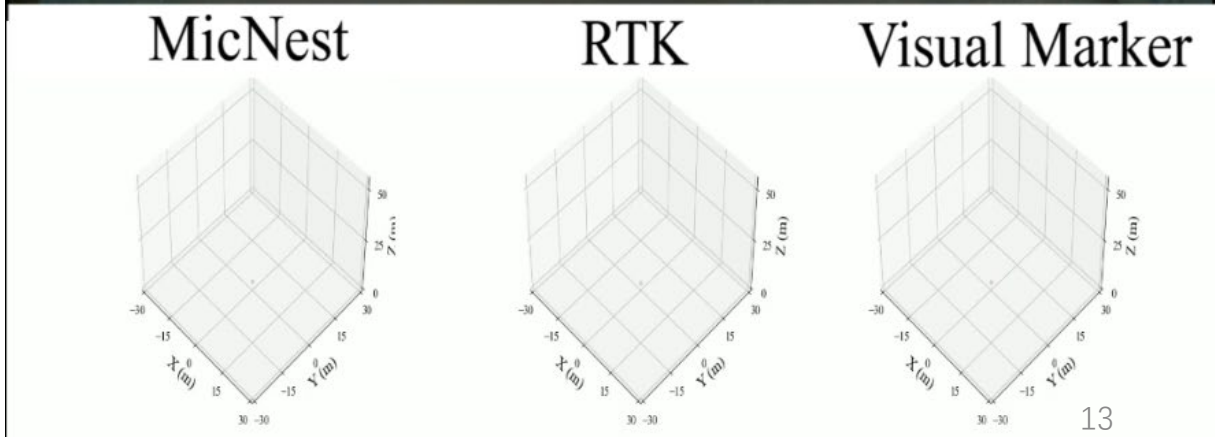
Evaluation



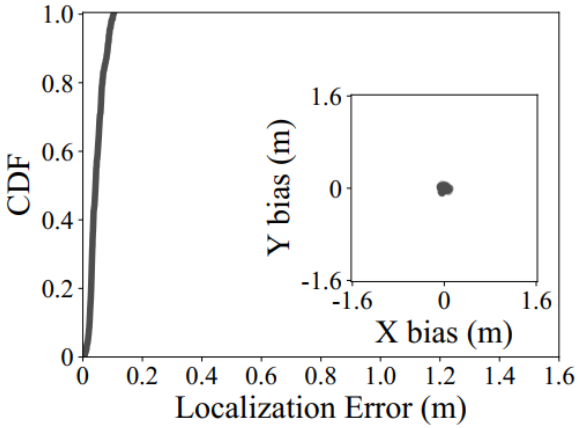
Baselines:

- **RTK**
- **Visual Marker**

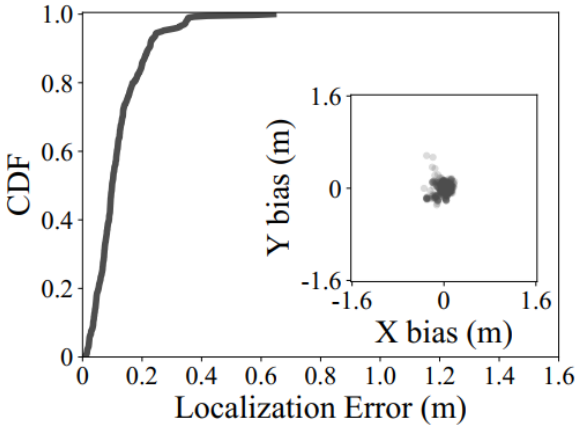




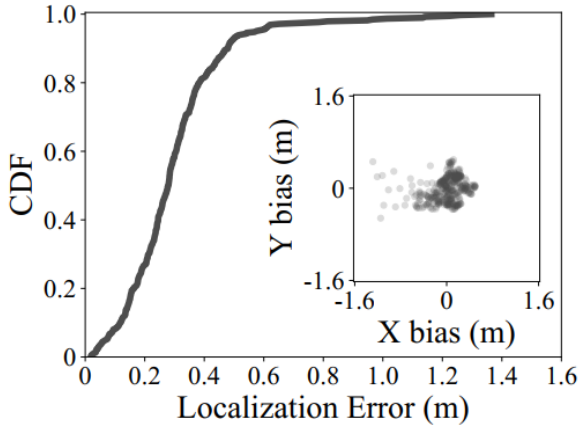
Impact of Altitude



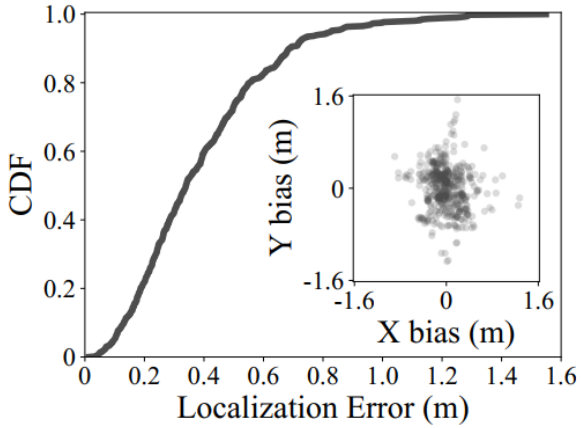
0m-20m altitude



20m-50m altitude



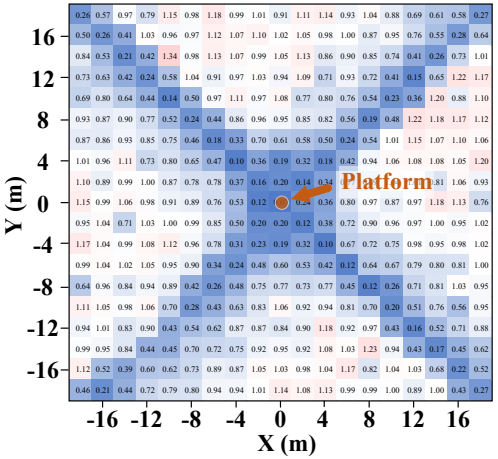
50m-80m altitude



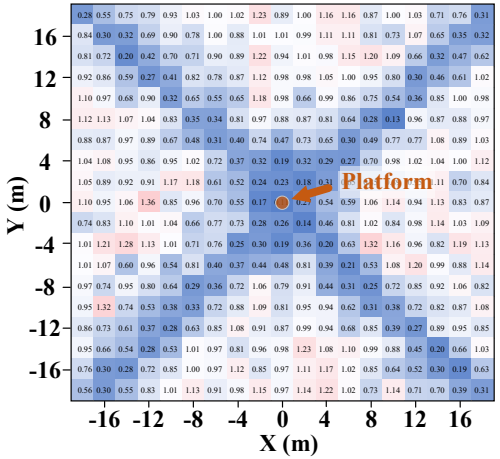
80m-120m altitude

Feature 1: localization error decreases as the altitude decreases

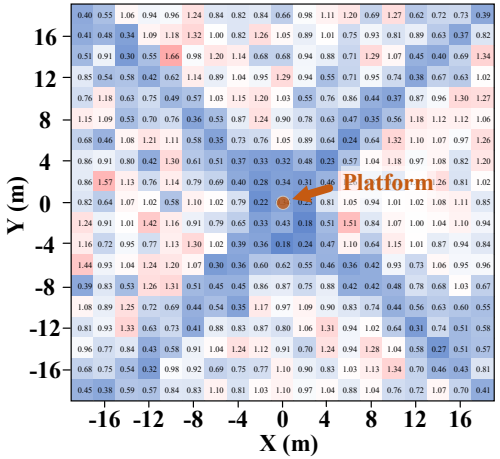
Impact of Horizontal Distance



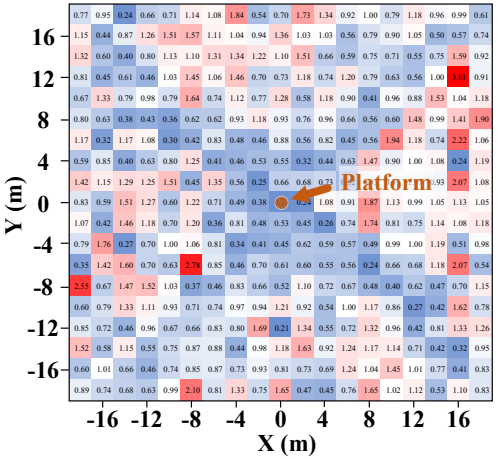
altitude 25m



altitude 50m



altitude 75m

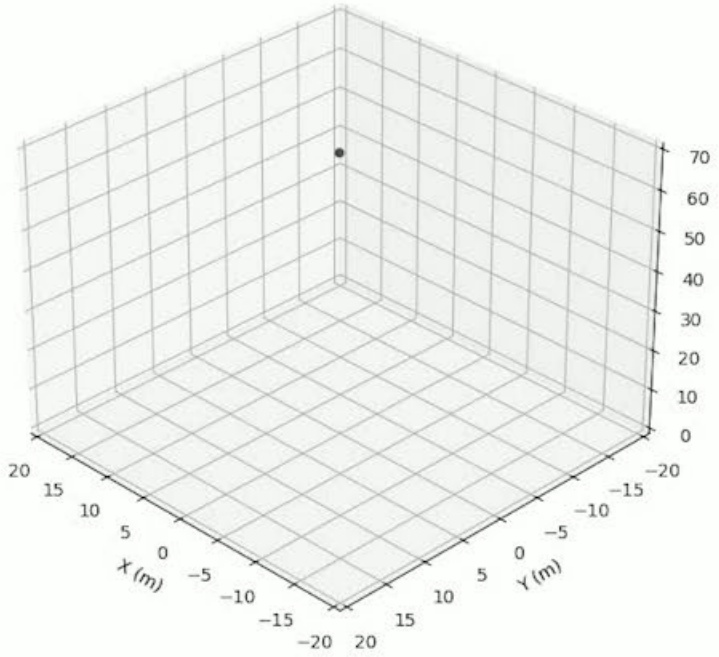


altitude 100m

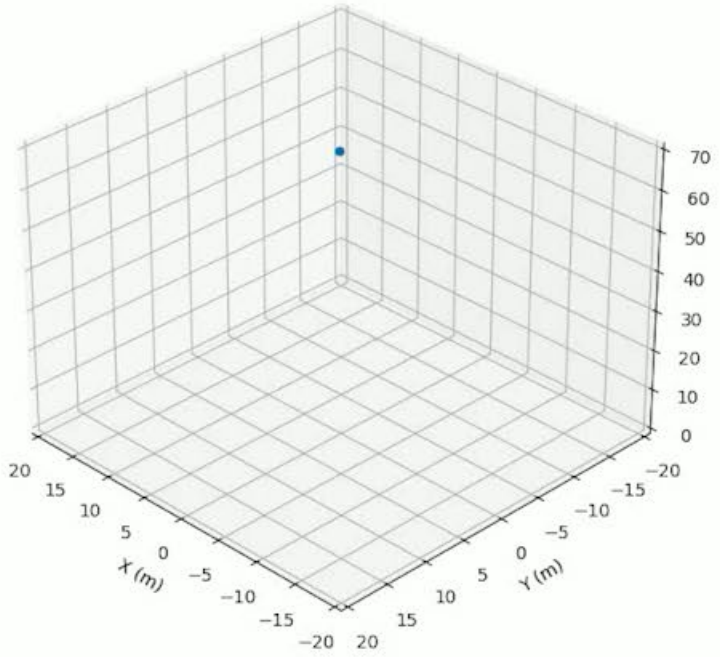
Feature 2: Localization error decreases as the drone approaches the platform

Navigating Drone Landing

MicNest

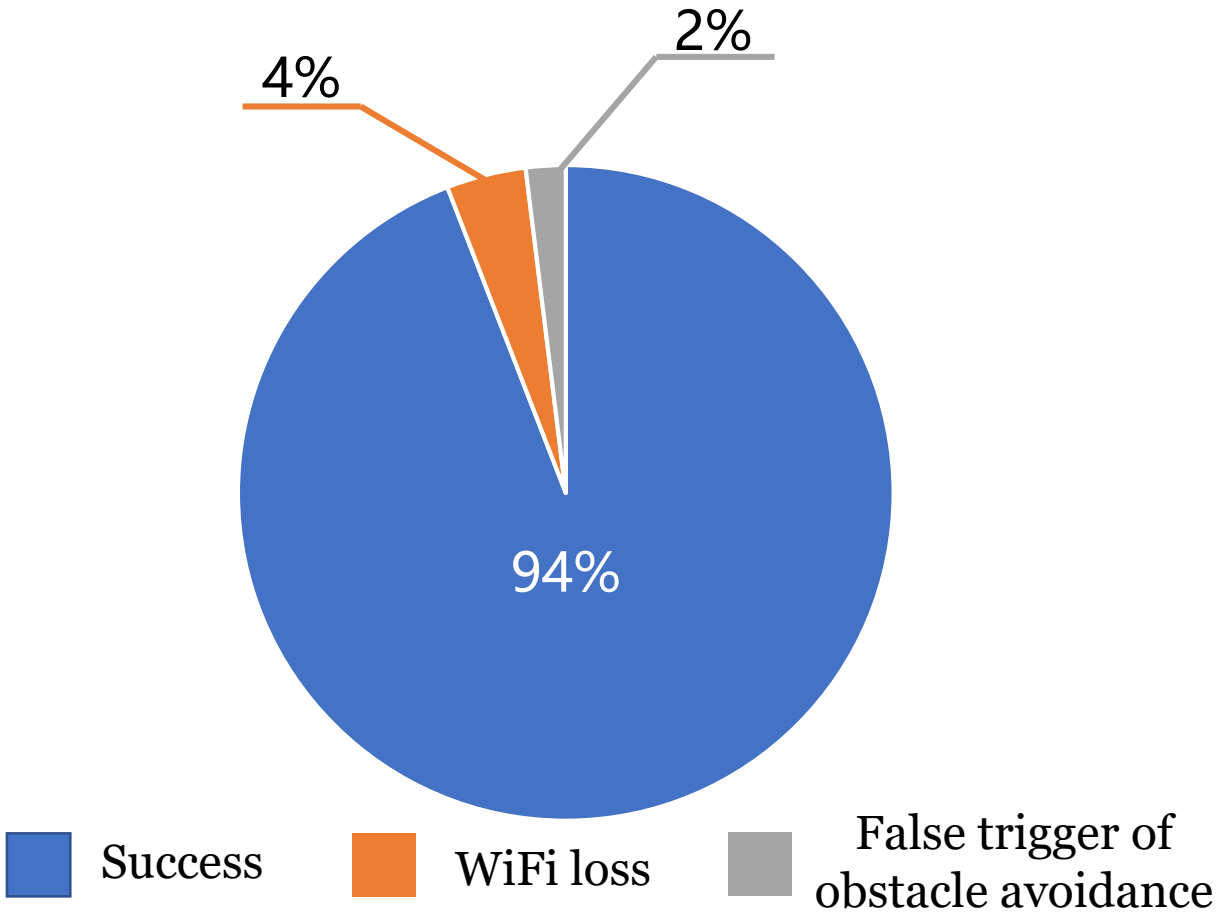


RTK

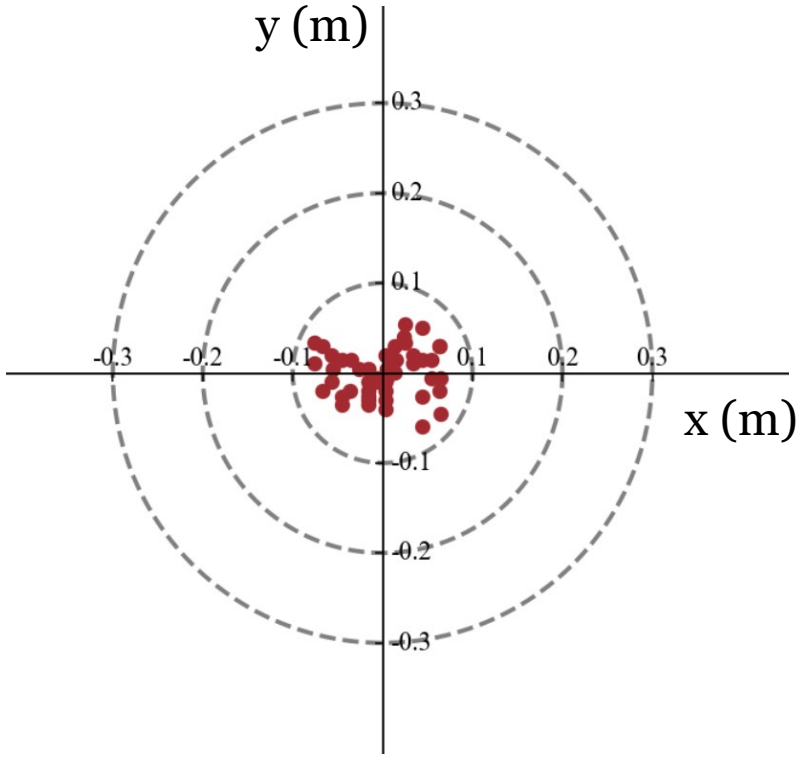


Playback Speed：3x

Navigating Drone Landing



Statistics (50 continuous flights)



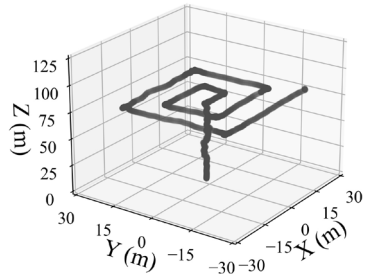
Distribution of landing points

MicNest can navigate drone landing **robustly and accurately**

Summary

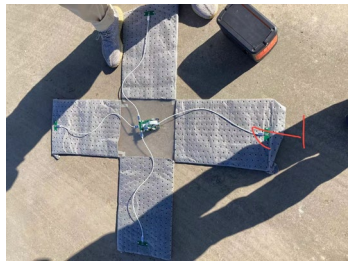
- **MicNest** enables precise landing of drones using acoustic signals.
- The key enabling technologies we present are **MFT**, a novel pulse detector that models the problem as a tree search problem
- MicNest is able to localize a drone **120 m** away with **0.53%** relative localization error at **20 Hz** location update frequency.

Milestones and Future Work



Real time localization

2021.10



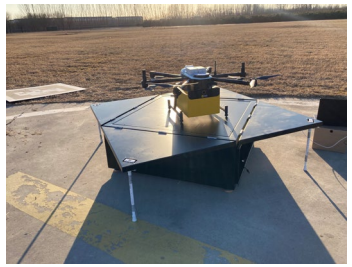
Initial microphone array

2021.12

500

Accumulated test flights

2022.01



New microphone array

2022.07

Approved for use in flight control systems

2022.07

Successful navigating landing

2022.08

100

Accumulated navigations

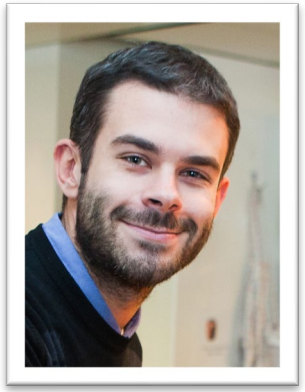
2022.09

Incorporating MicNest ...

2022.10 (ongoing)

Thank You!

Weiguo Wang

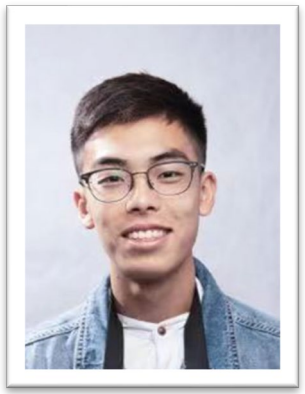


Luca Mottola

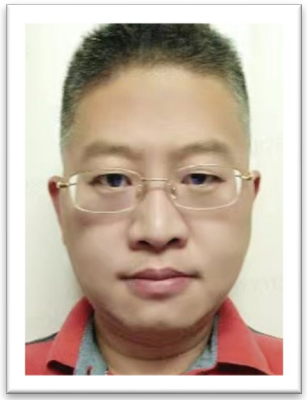
Yuan He

Jinming Li

Yimiao Sun



Shuai Li



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