

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



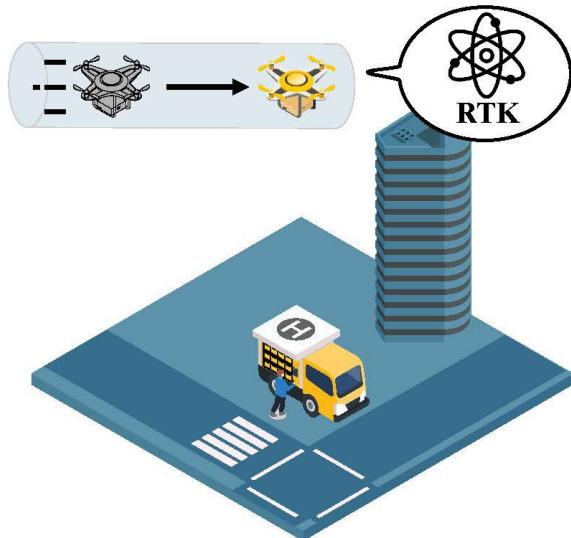
5. Land and dock onto the self-collection station



6. Fetch

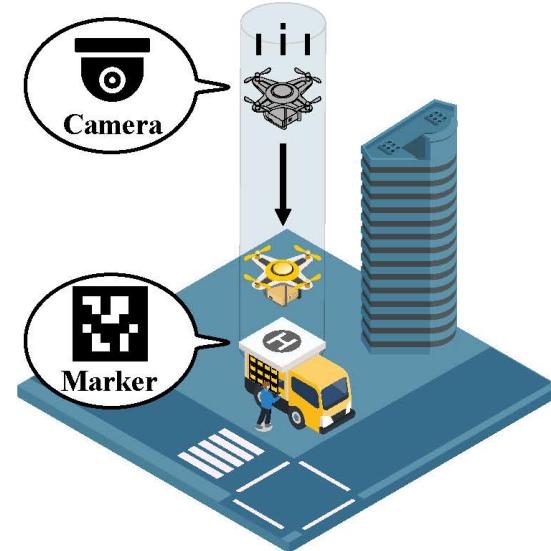
State-of-the-Art in Precise Landing

Step 1: Horizontal approach



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

Step 2: Vertical descent

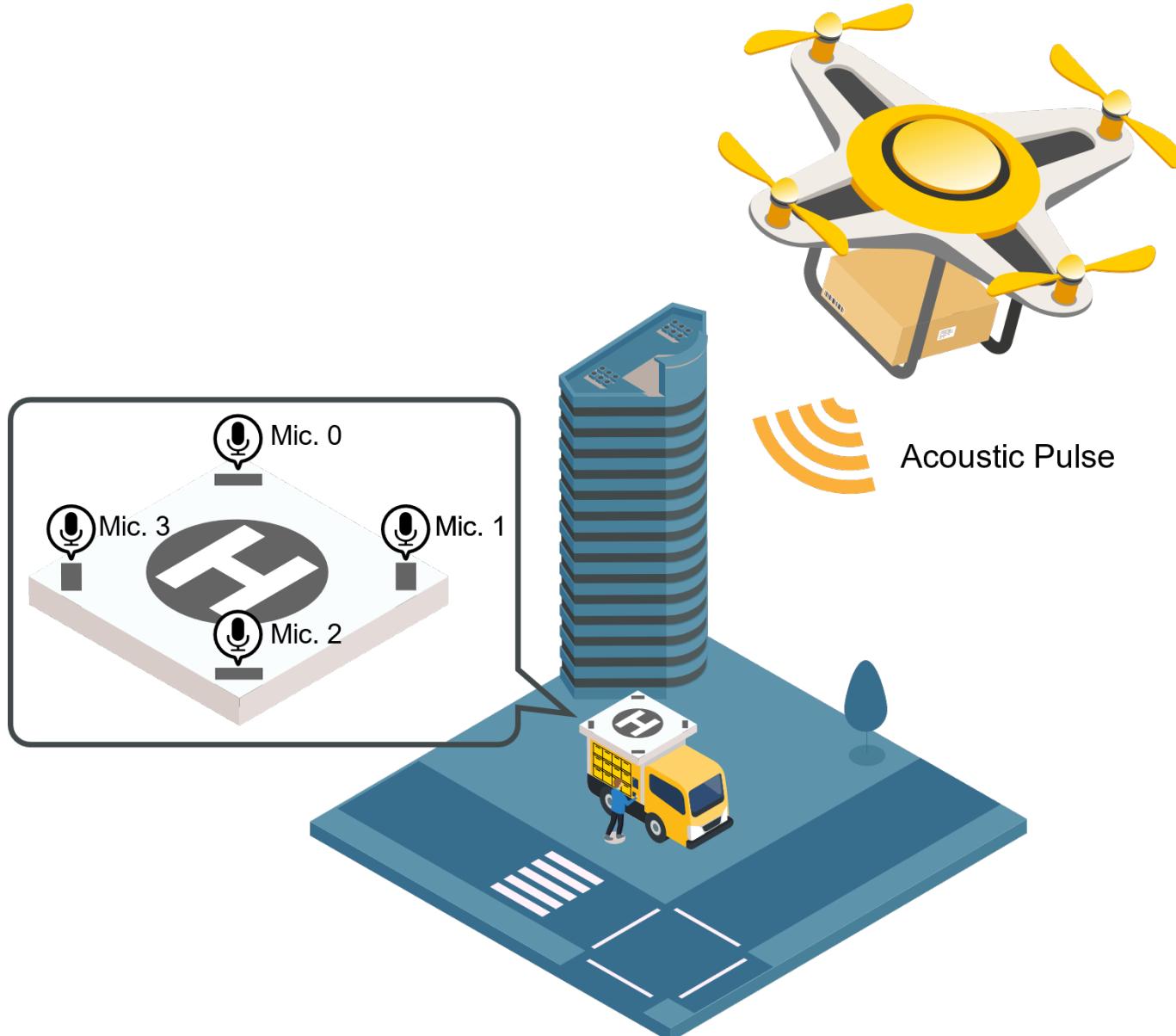


- ✓ High Precision
- ✗ Limited Coverage
- ✗ Sensitive to lighting conditions

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

MicNest:

Acoustic Localization System for Drone Landing

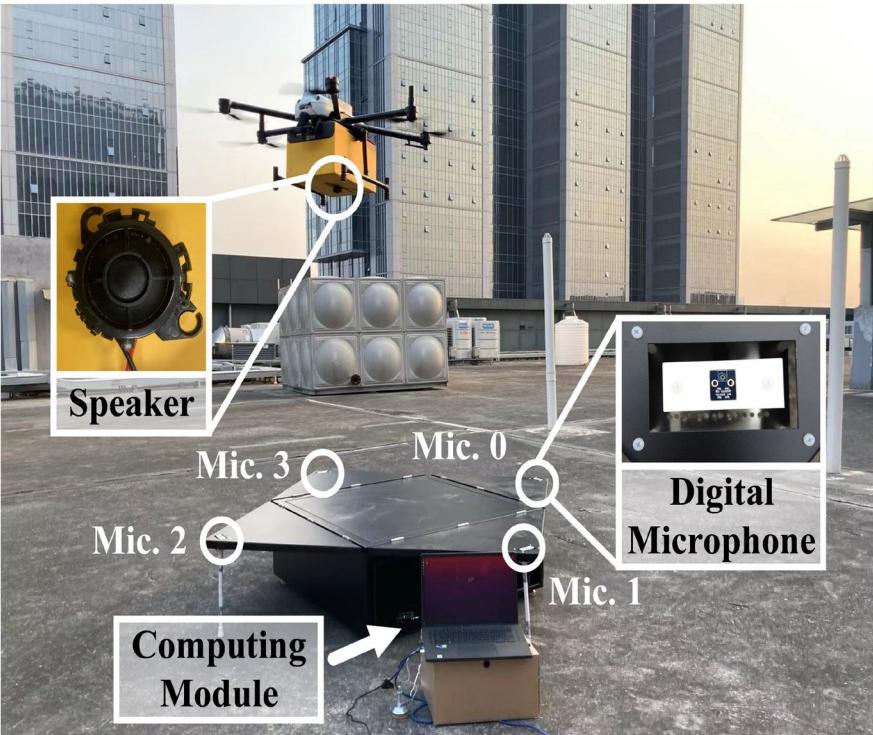


120 m
Operation Range

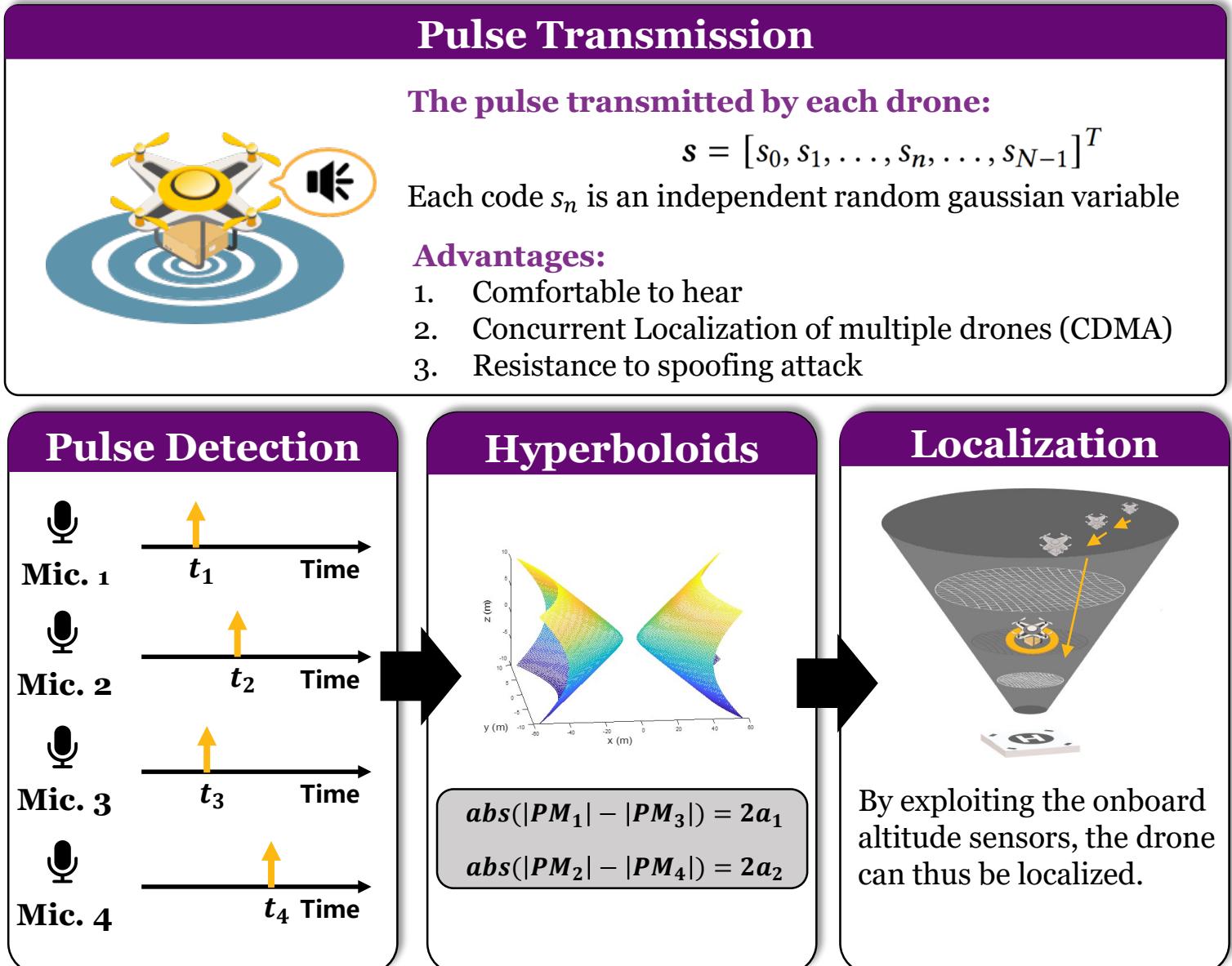
0.53%
Relative Localization Error

20 Hz
Location Update Rate

MicNest in a Nutshell



Hardware



Why Acoustics?

Spatial Resolution

- The **spatial resolution R** (absolute ranging resolution) of wireless signal is proportional 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

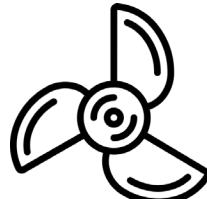
- Bandwidth: 24 KHz
- Spatial Resolution: **0.7 cm**

Challenges

Low SNR



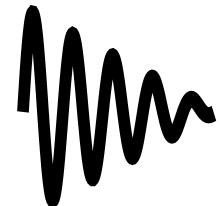
Limited
Tx Power



Strong
Interference



High
Noise Floor



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

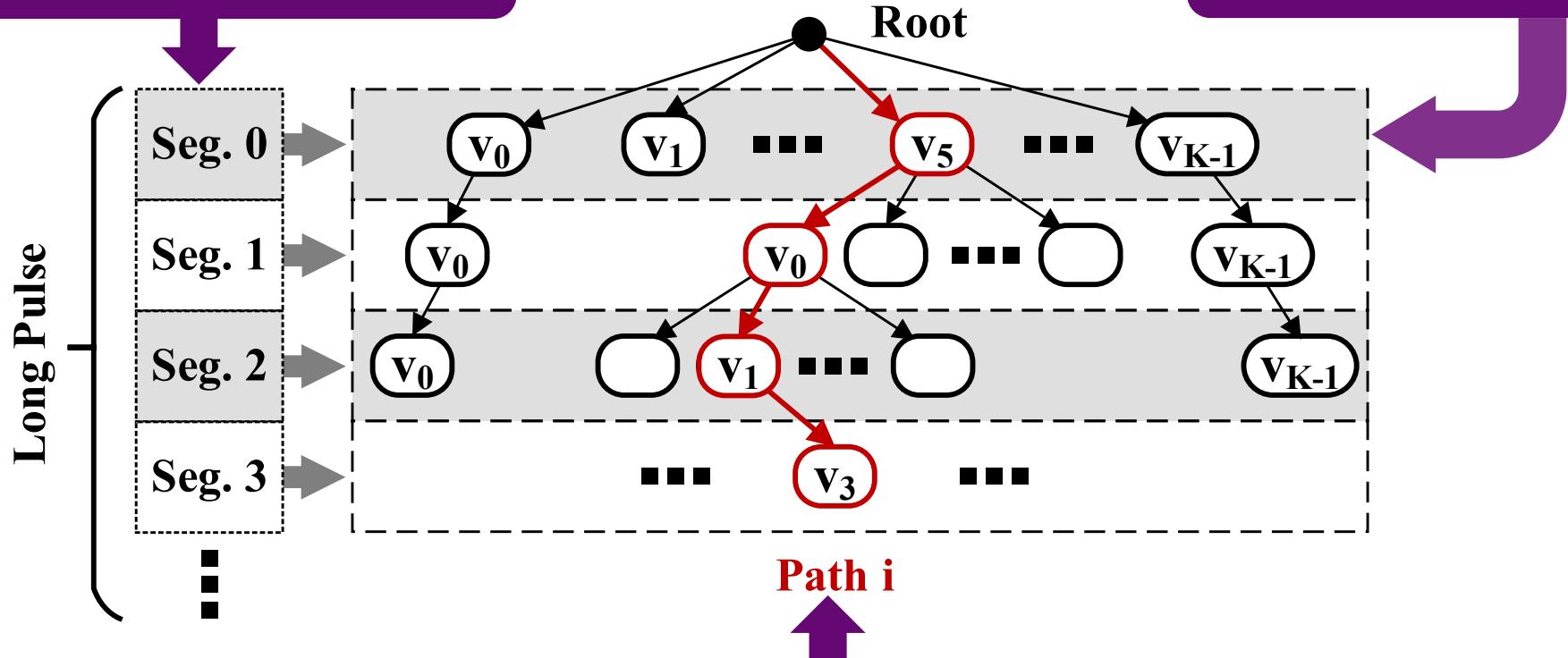


- MicNest is used to navigate moving drones.
- Signal processing must withstand the latency constraint imposed by the nature of flight control loops.

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

Matched Filter Tree (MFT)

cut one pulse into
multiple short segments



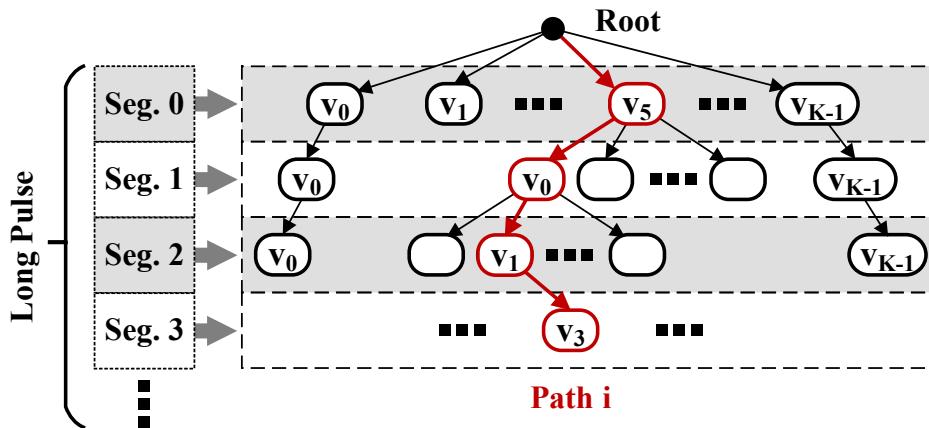
nodes at each level correspond
to the possible drone velocities

nodes along a tree path represent a
set of compensation coefficients

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

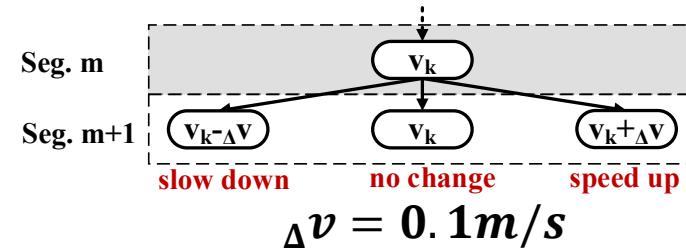
- For each tree path, perform the following operations:
 1. **Compensate** segments by using coefficients
 2. **Concatenate** compensated segments into a new pulse template
 3. **Correlate** the new template with the received signal.
- After visiting all paths, select the tree path with the maximum correlation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

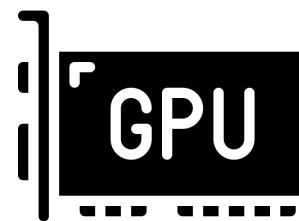


reduce search space



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.

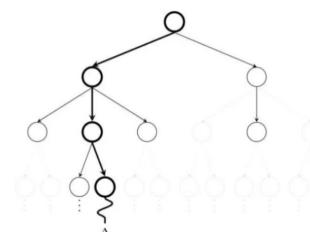


reduce time cost of search path



Heuristic Search

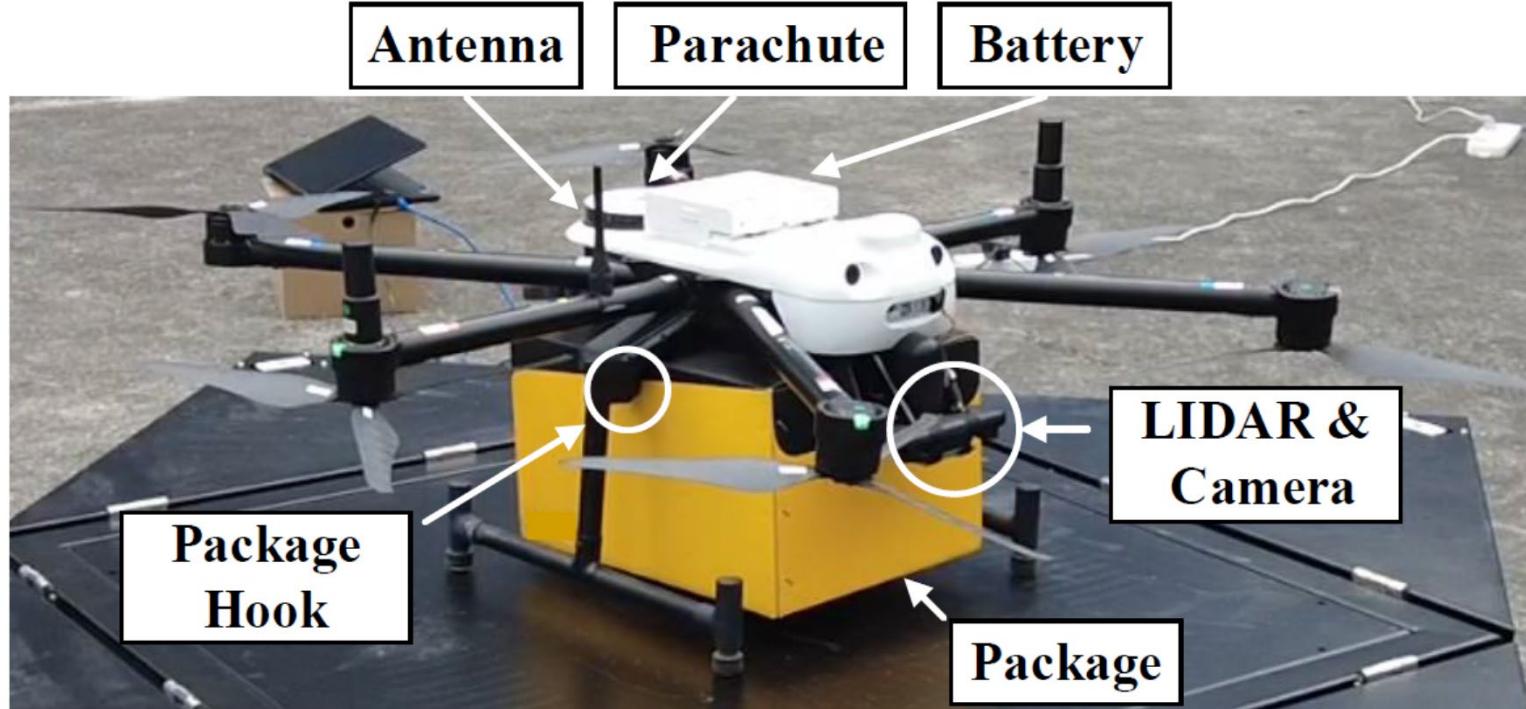
- This idea is similar to **Monte-Carlo Tree Search (MCTS)**
- We can exploit visiting history to quickly dive towards the solution.



reduce total visit count



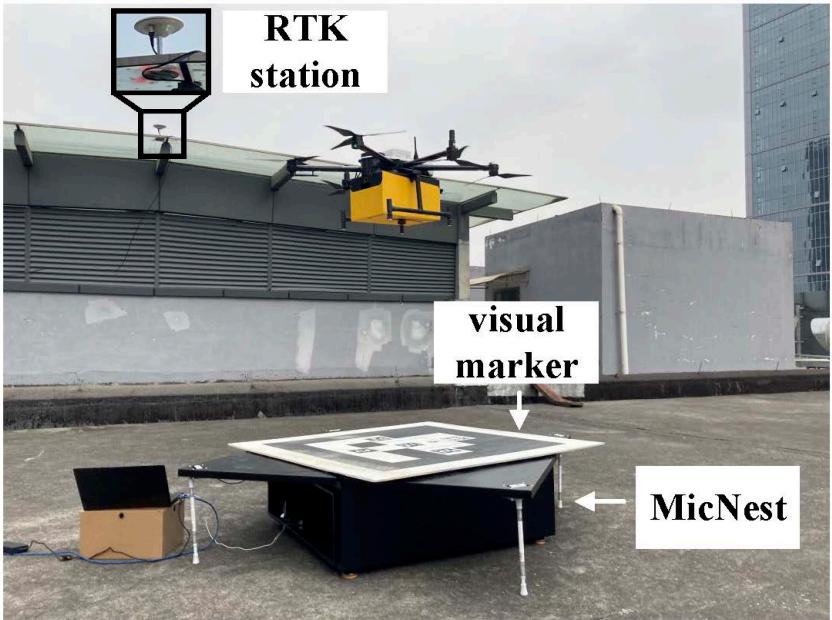
Delivery Drone



美团 Meituan

Evaluation

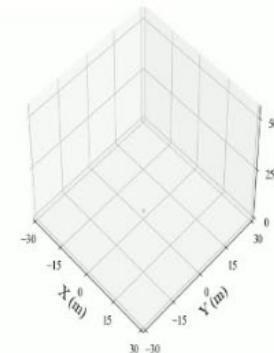
Playback Speed: 3x



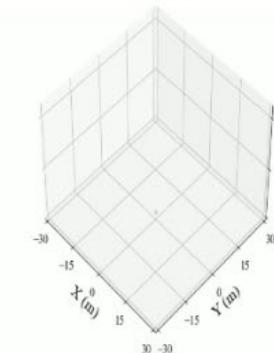
- Baselines:**
- RTK
 - Visual Marker

Downward-facing
Camera

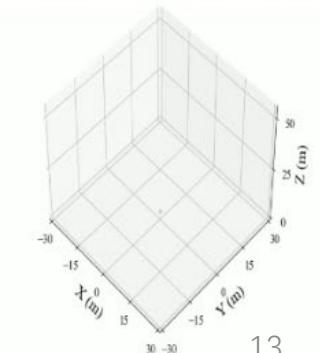
MicNest



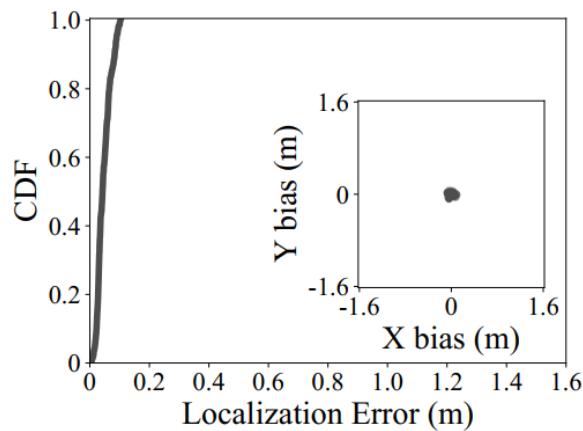
RTK



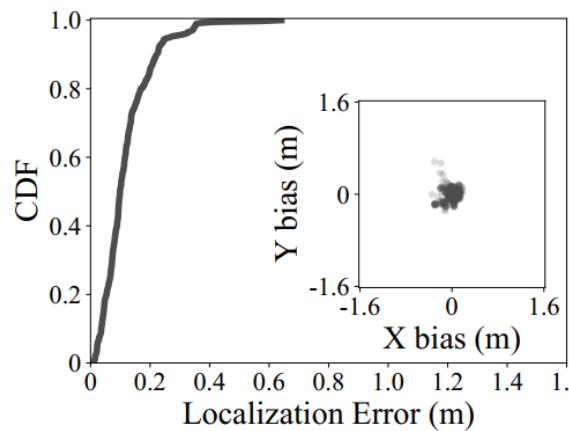
Visual Marker



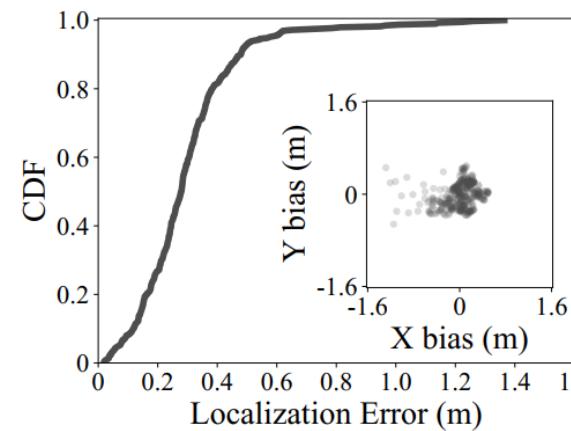
Impact of Altitude



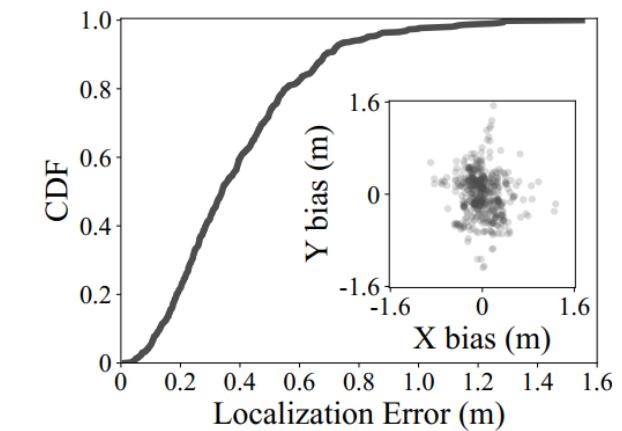
0m-20m altitude



20m-50m altitude



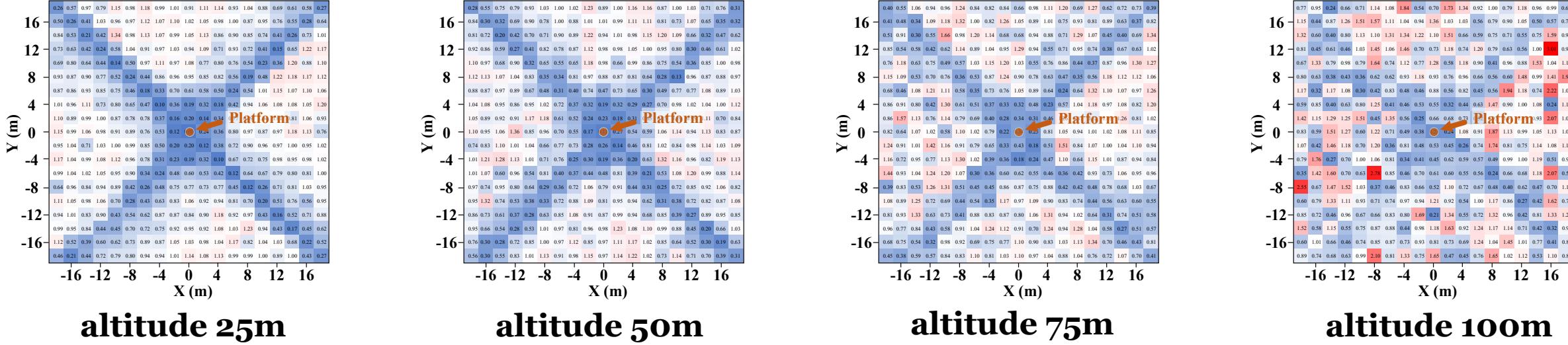
50m-80m altitude



80m-120m altitude

Feature 1: localization error decreases as the altitude decreases

Impact of Horizontal Distance

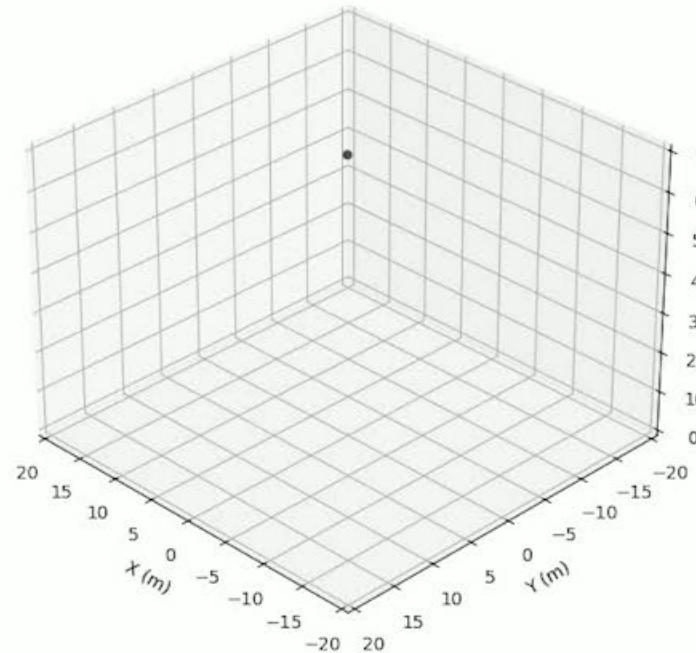


Feature 2: Localization error decreases as the drone approaches the platform

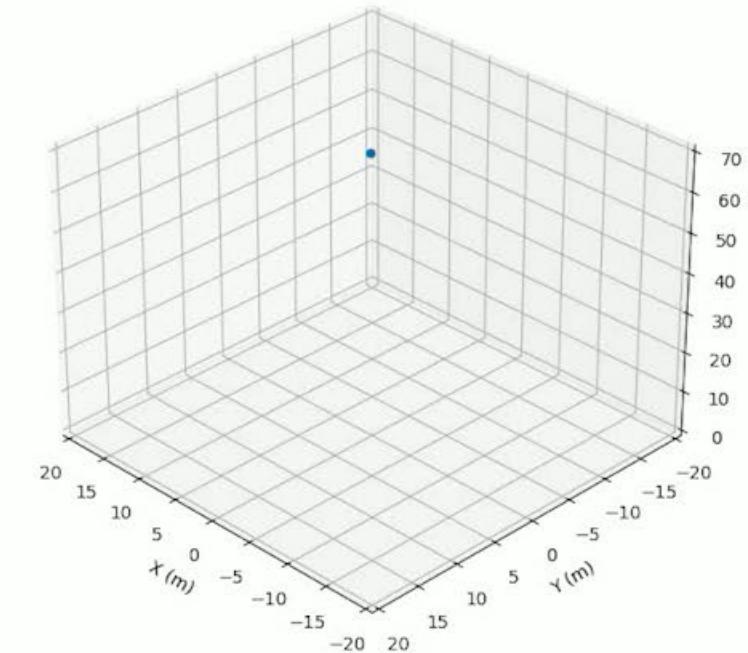
Navigating Drone Landing



MicNest

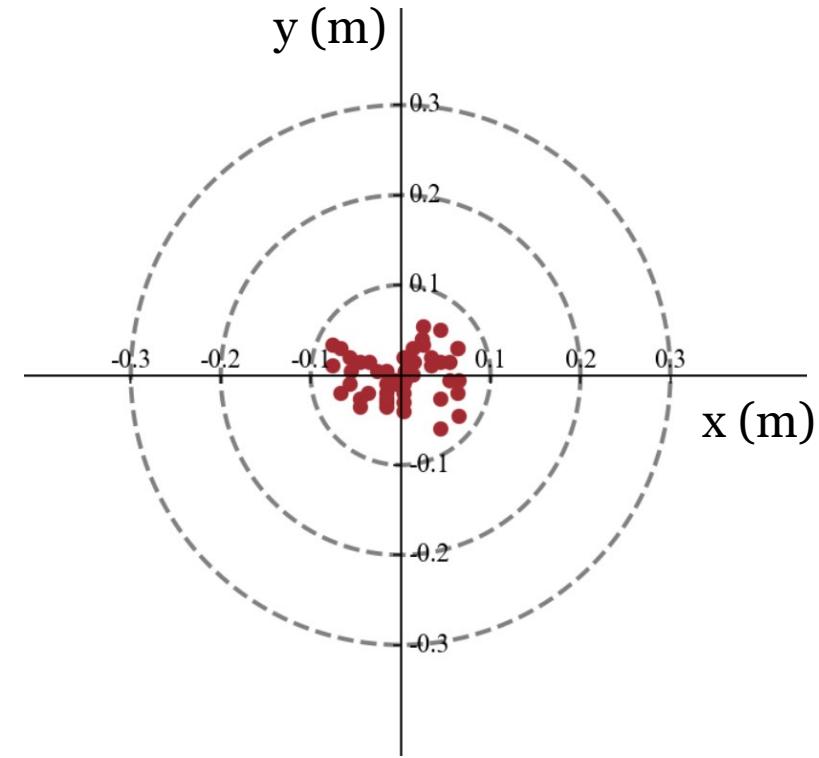
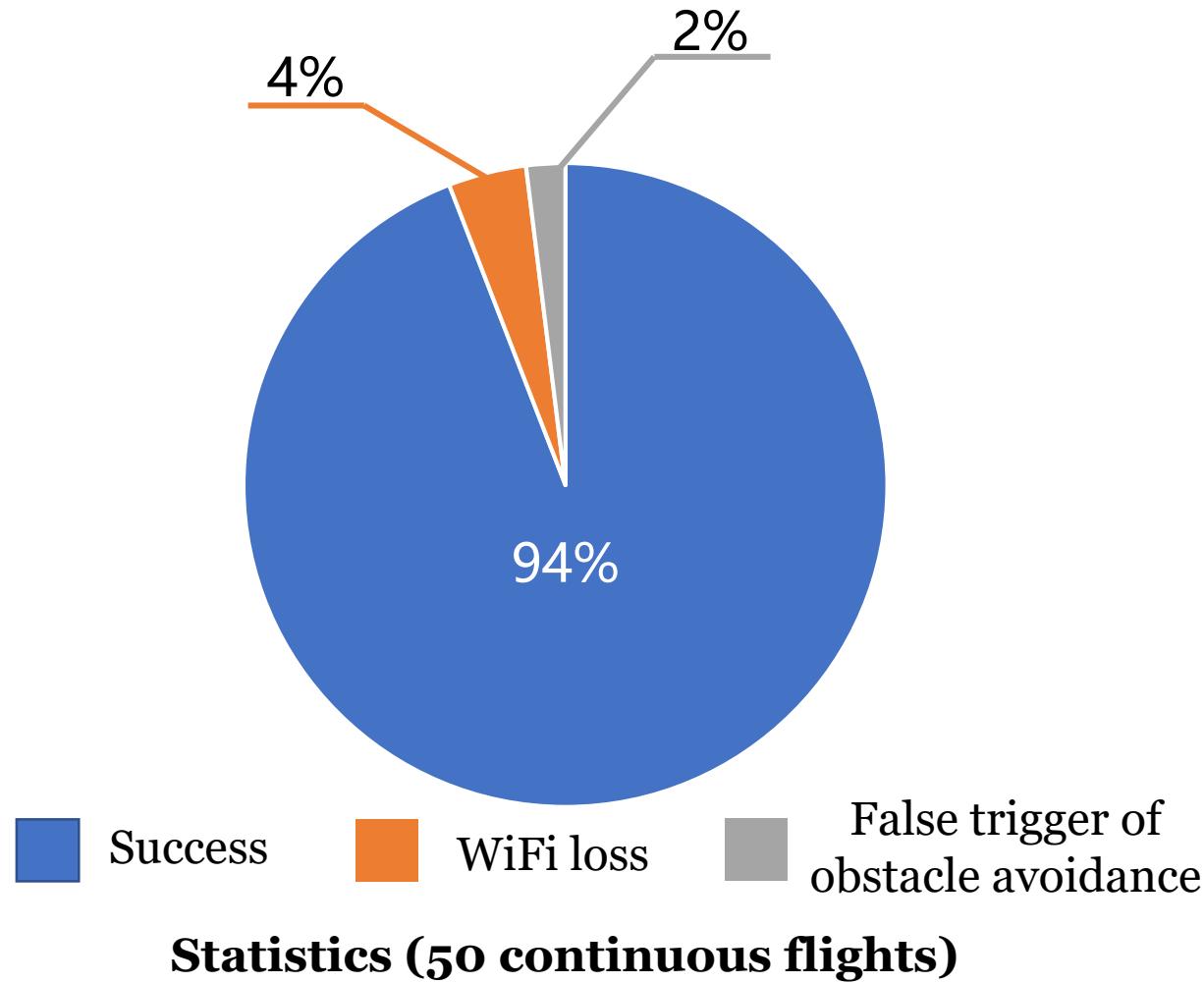


RTK



Playback Speed: 3x

Navigating Drone Landing



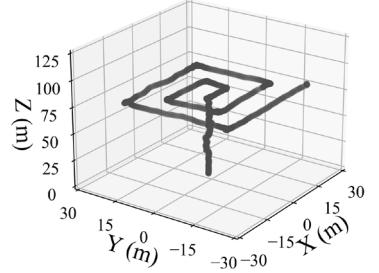
Distribution of landing points

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

500

Accumulated
test flights



Successful
navigating landing



Incorporating
MicNest ...

2021.10

2021.12

2022.01

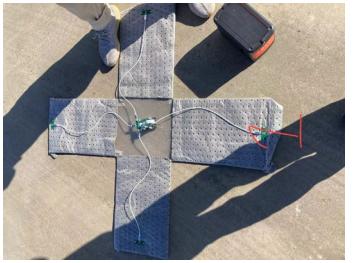
2022.07

2022.07

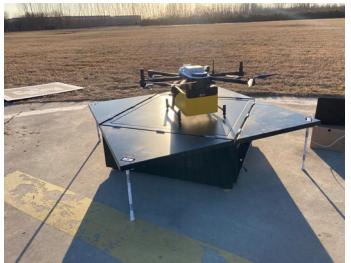
2022.08

2022.09

2022.10
(ongoing)



Initial
microphone array



New
microphone array



Approved for use
in flight control
systems

100

Accumulated
navigations



Thank You!



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