MilliSign:

mmWave Based Passive Signs for Guiding UAVs in Poor Visibility Conditions

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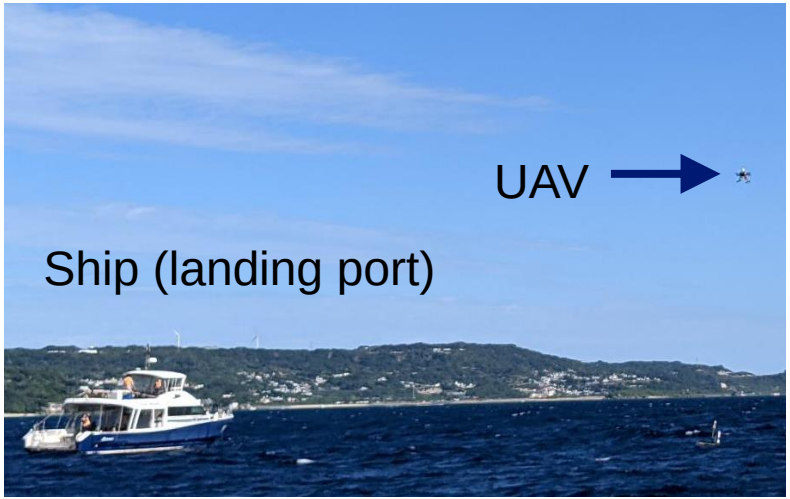
UAVs as Future Infrastructure

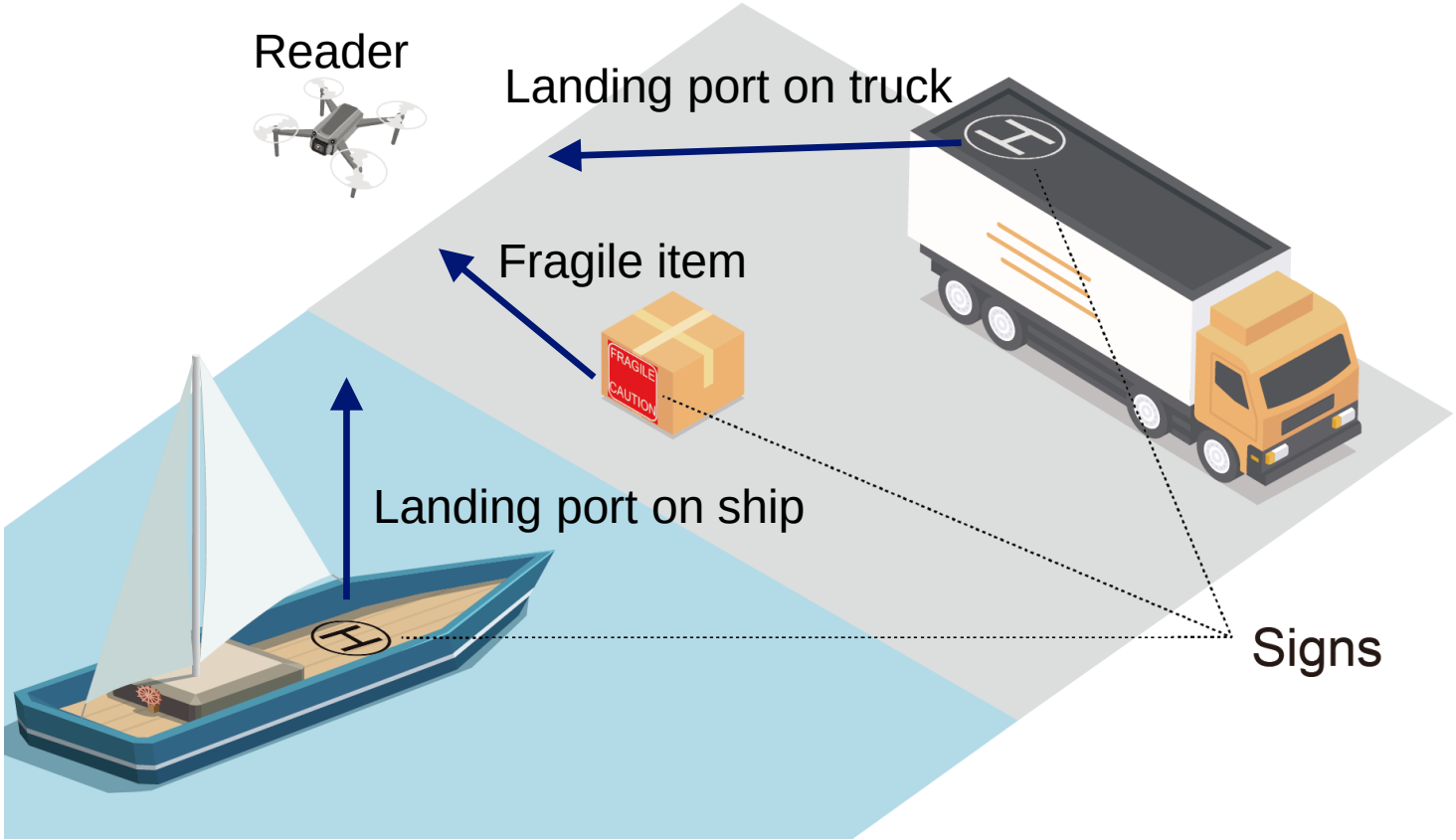
Logistics

Environmental monitoring

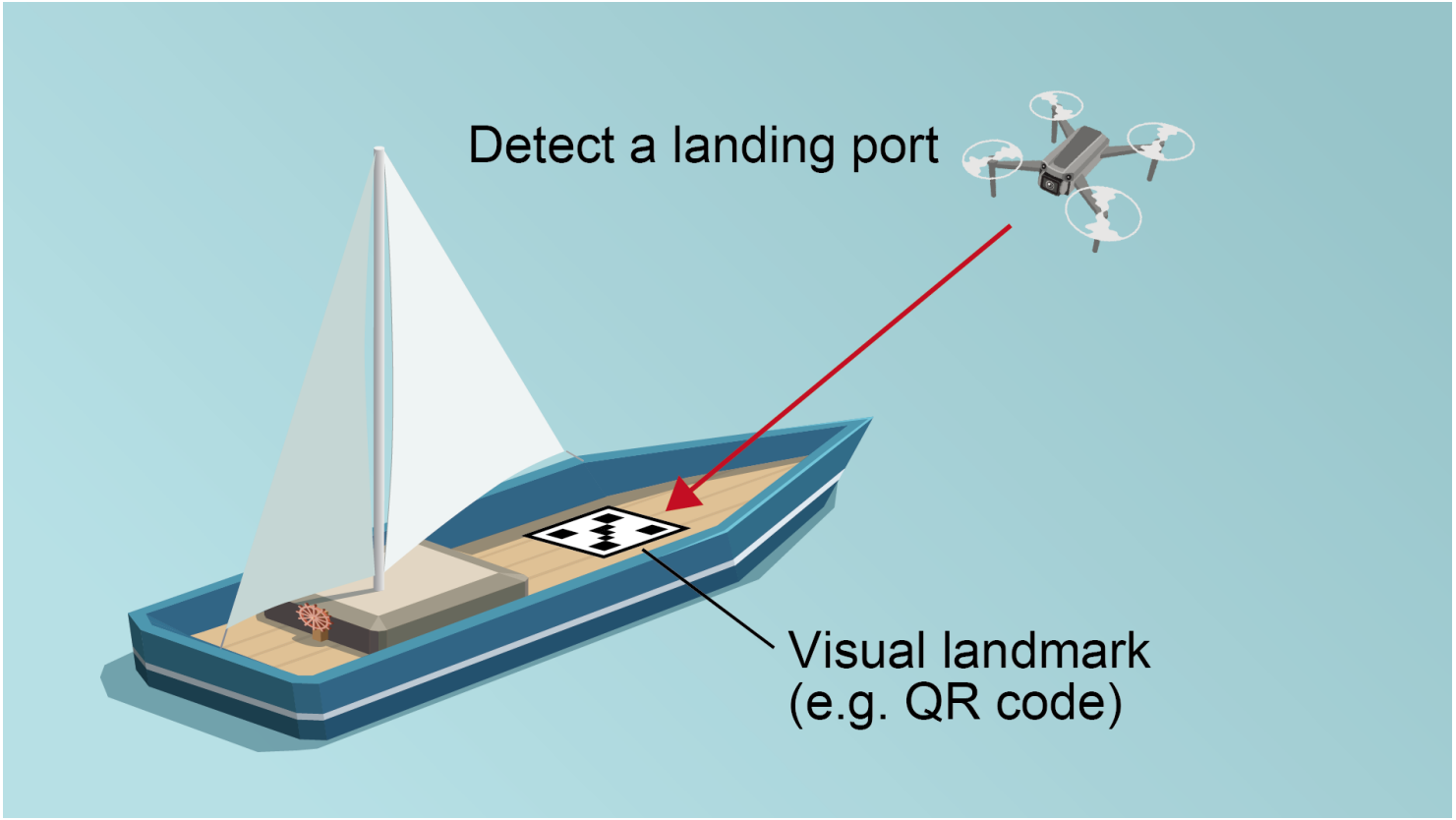


All-day / all-weather operation is critical.

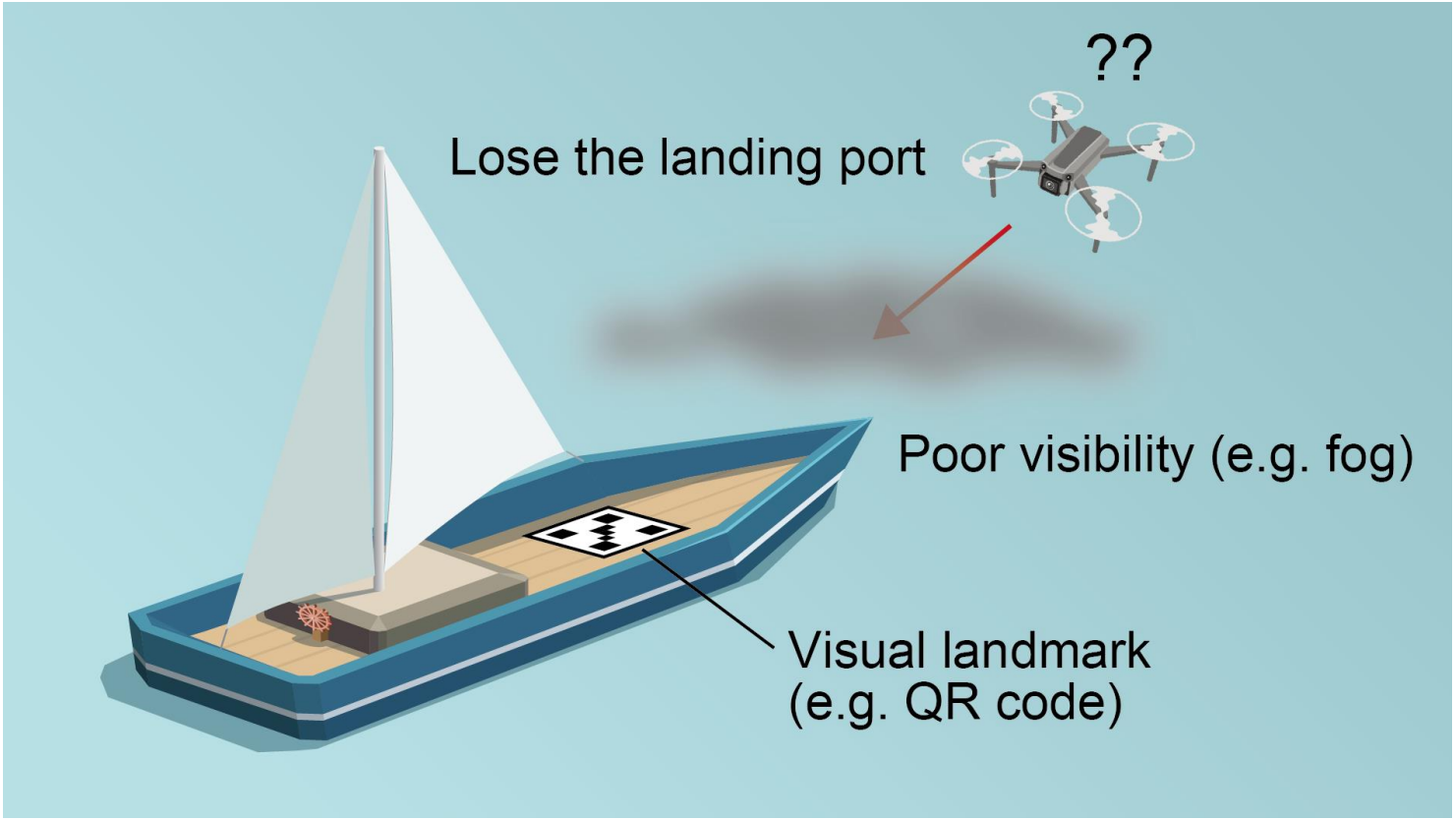
Signs for Autonomous Flight



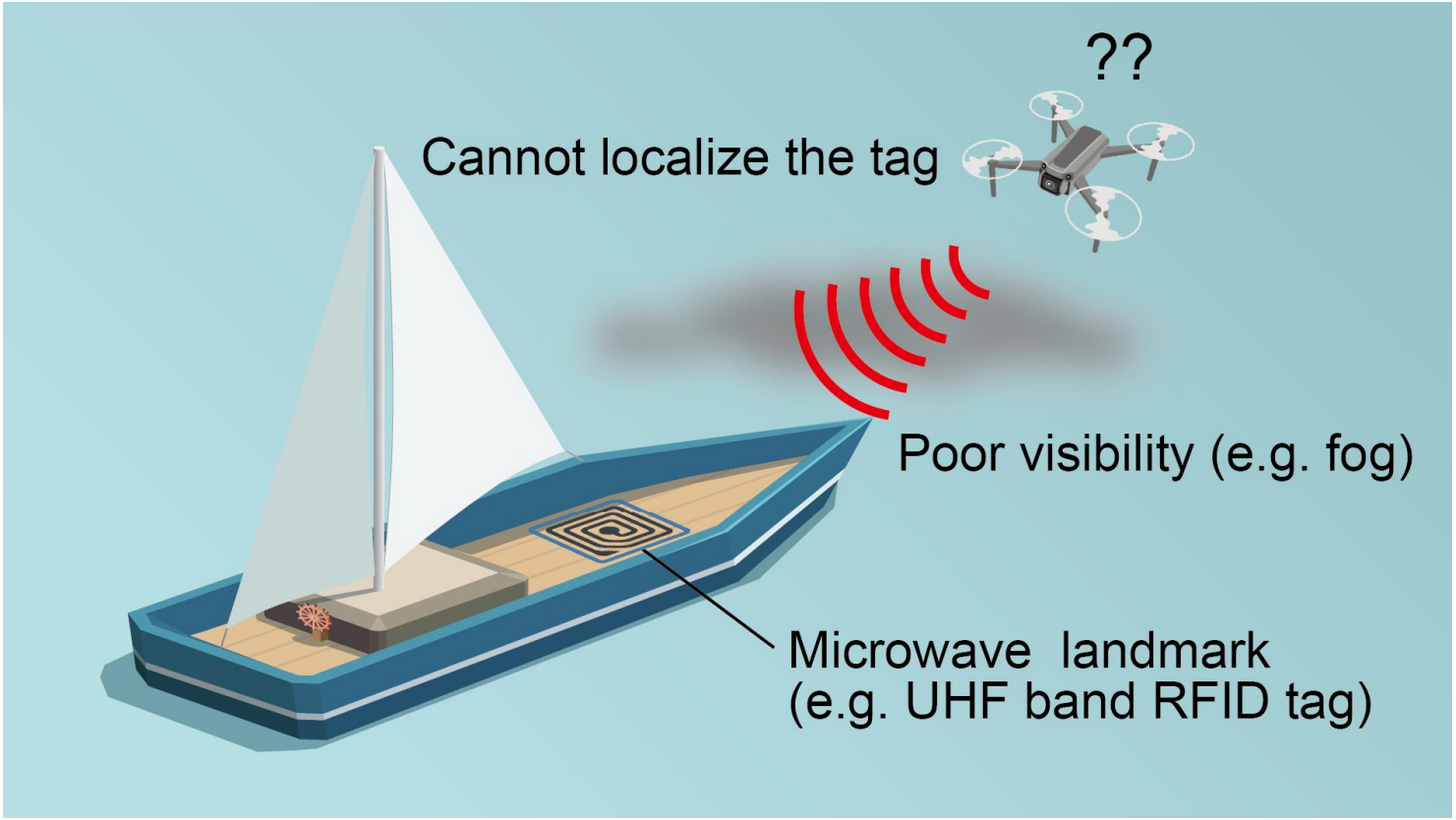
Challenges in Poor Visibility Conditions



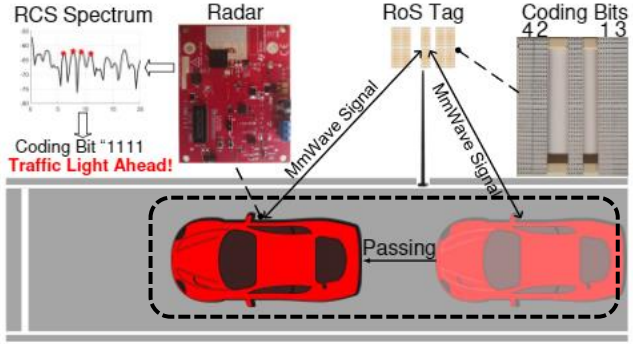
Challenges in Poor Visibility Conditions



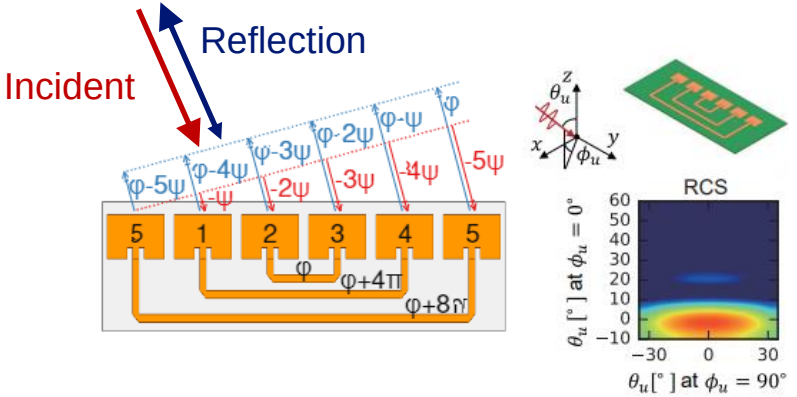
Challenges in Poor Visibility Conditions



Previous Work: mmWave Based Passive Signs



SAR-based reader [1]
Synthetic Aperture Radar



Van Atta array (retroreflector) [2]

Problem 1:
Requires multiple readouts.

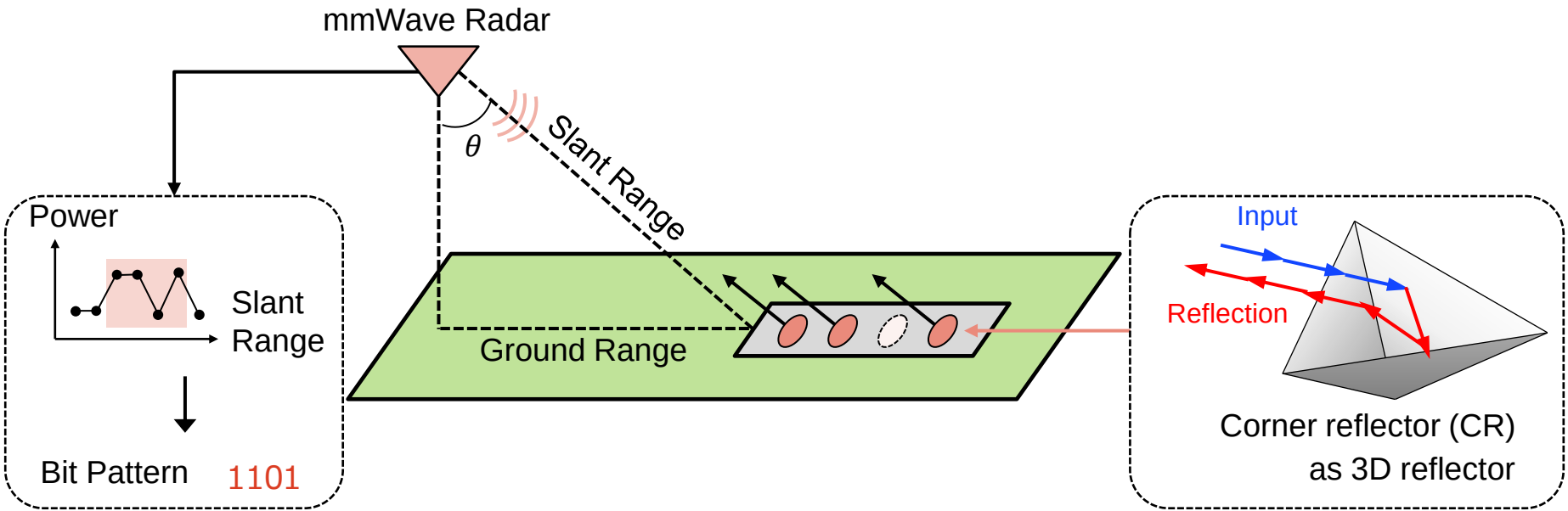
Problem 2:
Read range is limited to 2D plane.

[1]: Nolan, John, et al . *ACM SIGCOMM*. 2021. [2]: Soltanaghaei, Elahe, et al. ACM MobiCom. 2021.

MilliSign: mmWave Based Signs for UAVs

YouTube URL (42 sec ~ 75 sec):
https://www.youtube.com/watch?v=7SezvxK_vrY

Key Features of MilliSign



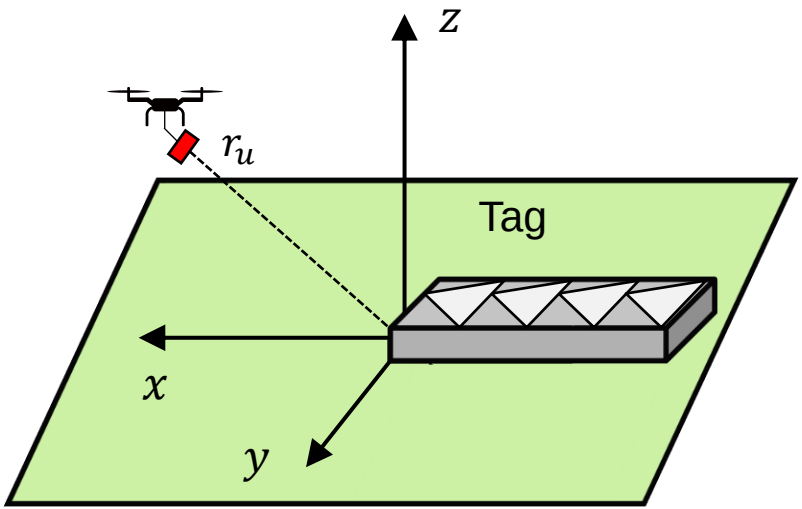
Slant range radar readout

-> One-shot readout of dense patterns.

Corner reflector-based RFID tag

-> Wide 3D read range.

Challenge: Compact Tag Size

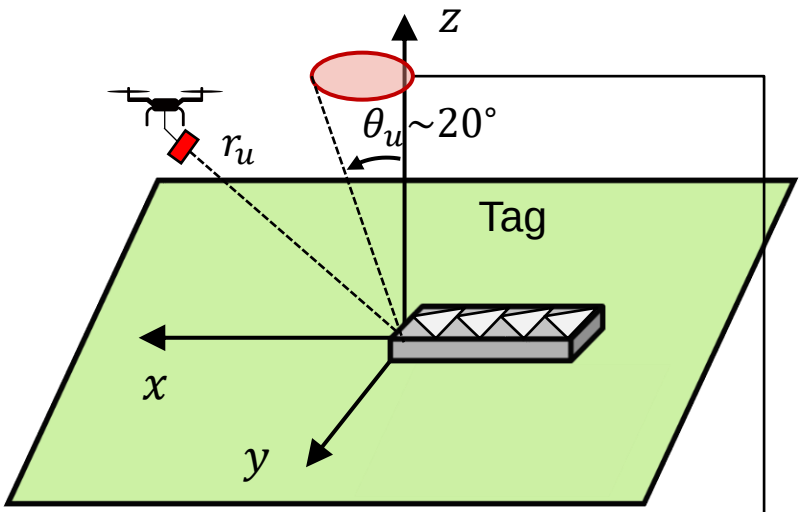


(i): Tradeoff between tag size and distance

Read Distance

Compact and
Flexible Tag Size

Challenge: Limited Read Range

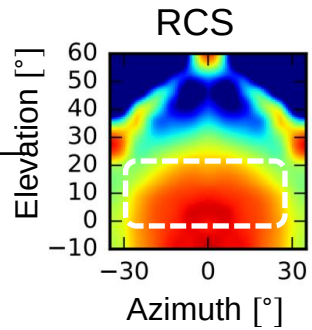


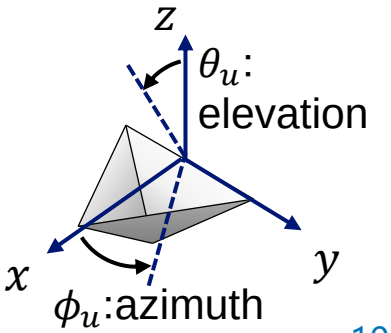
(i): Tradeoff between tag size and distance

Read Distance

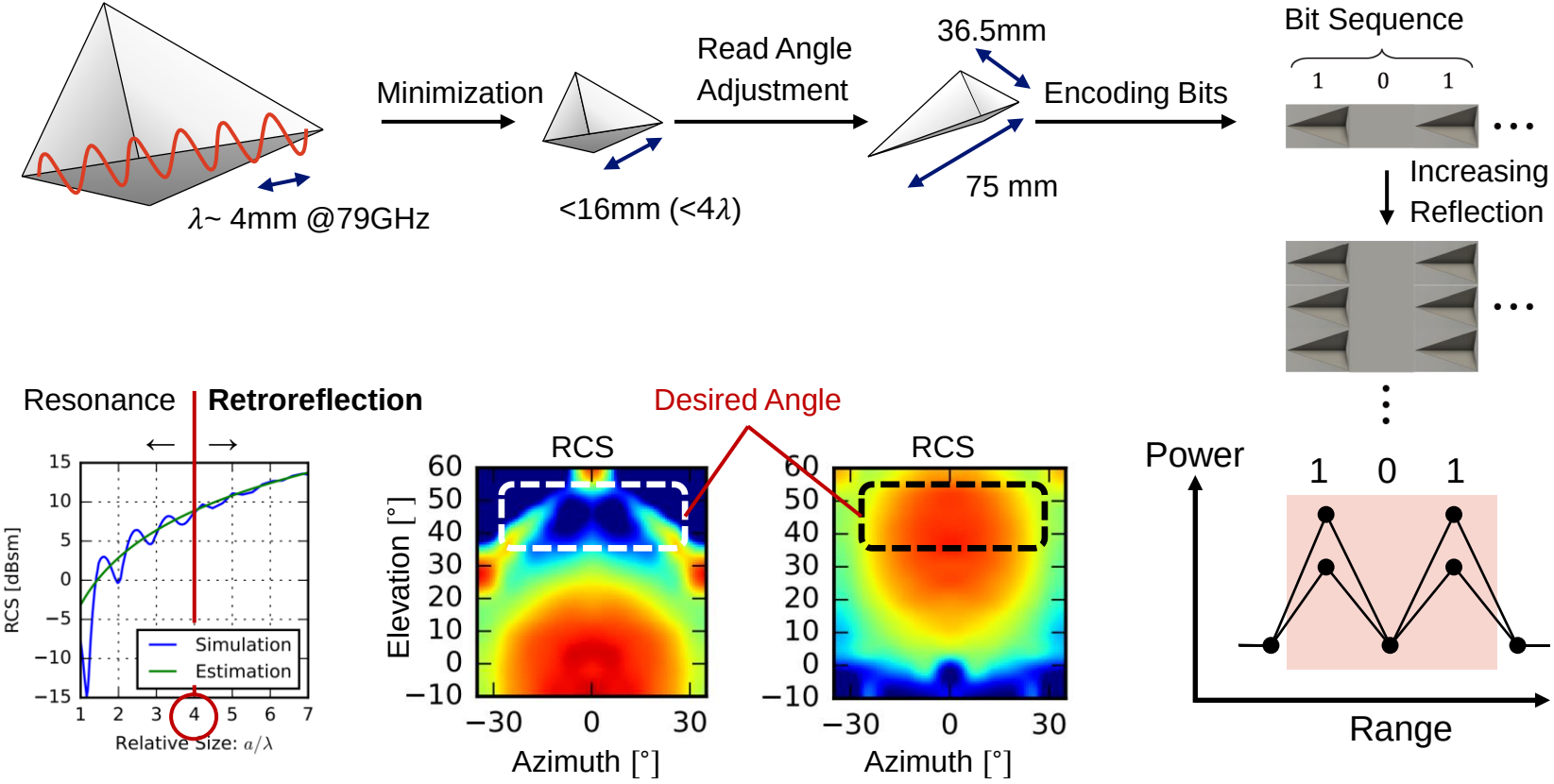
Compact and
Flexible Tag Size

(ii): Narrow angle range in elevation

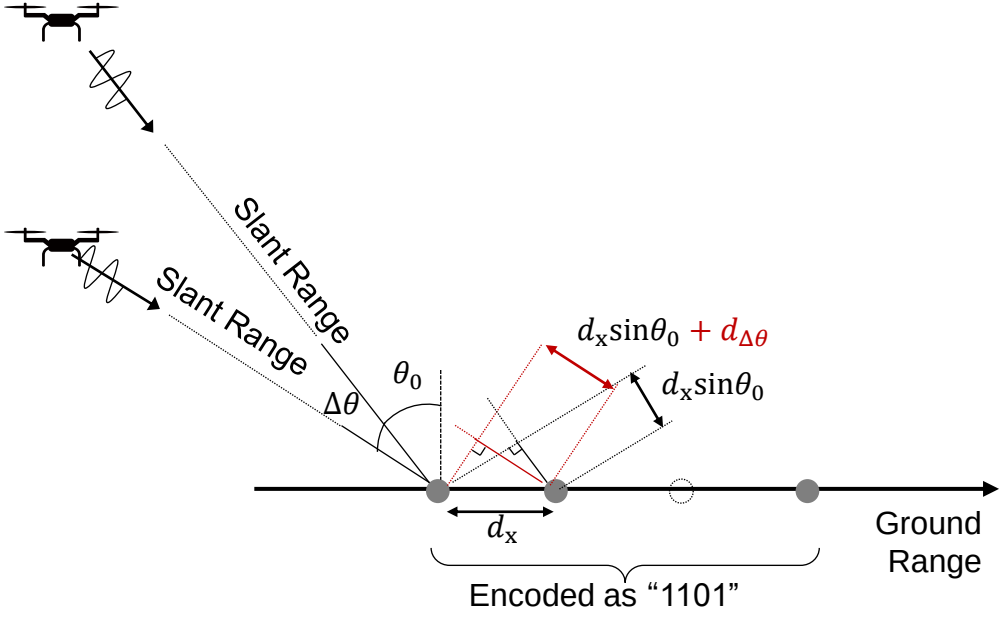


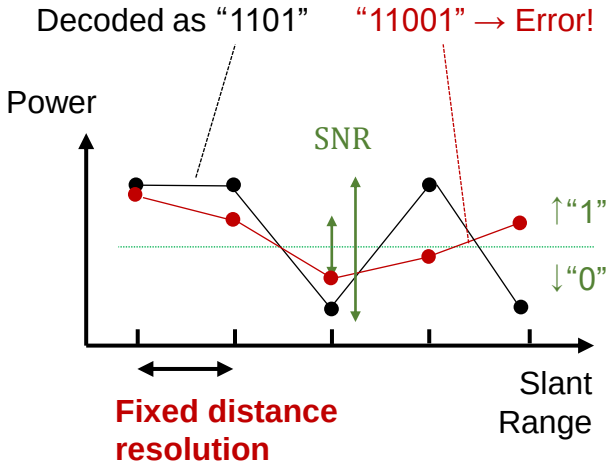


Read Range Design and Encoding Bits



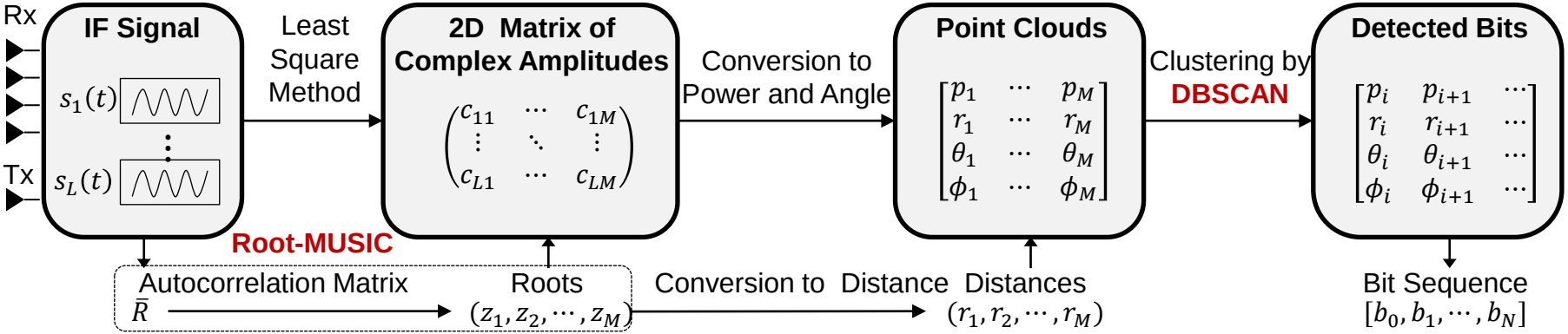
Challenge: Reading Out Dense Patterns

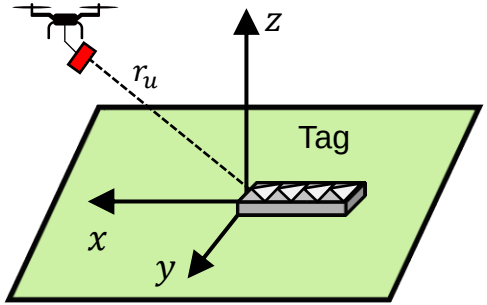


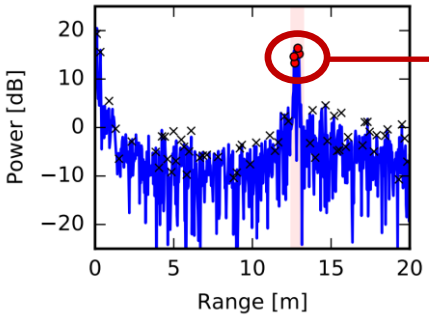


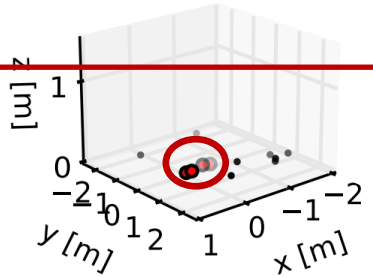
Detected spatial pattern changes with UAV’s position
→ Dense bits cause readout error

Signal Processing Pipeline

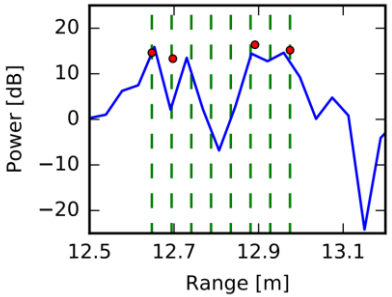








"11000101"

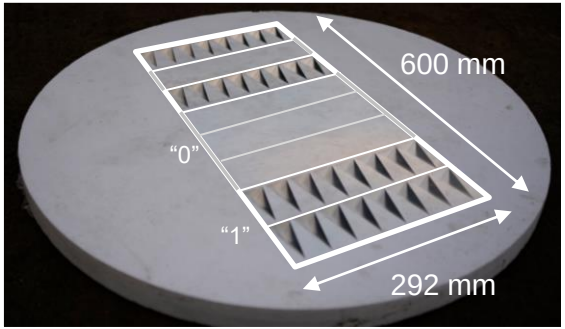


Off-grid bit detection and accurate tag localization

Experimental Setup

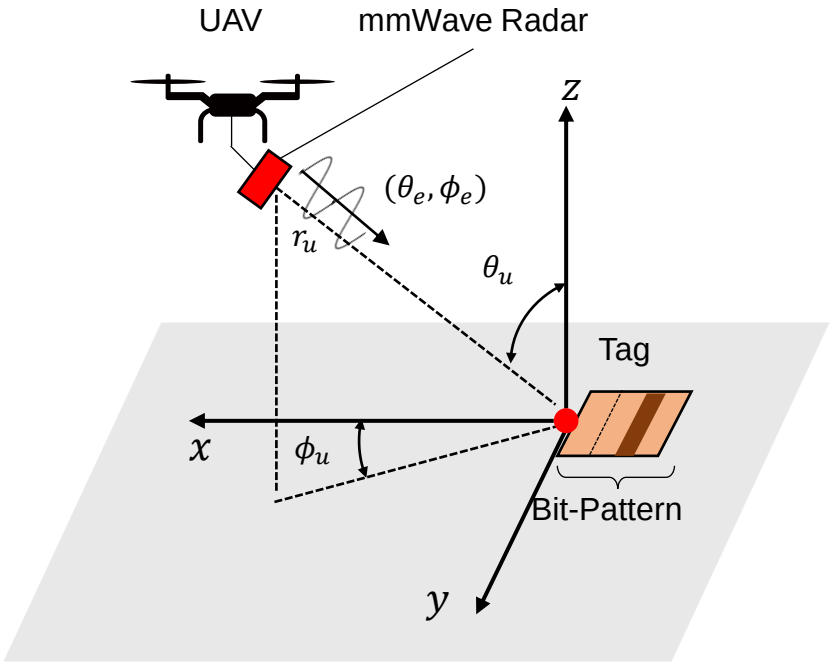
mmWave mounted UAV

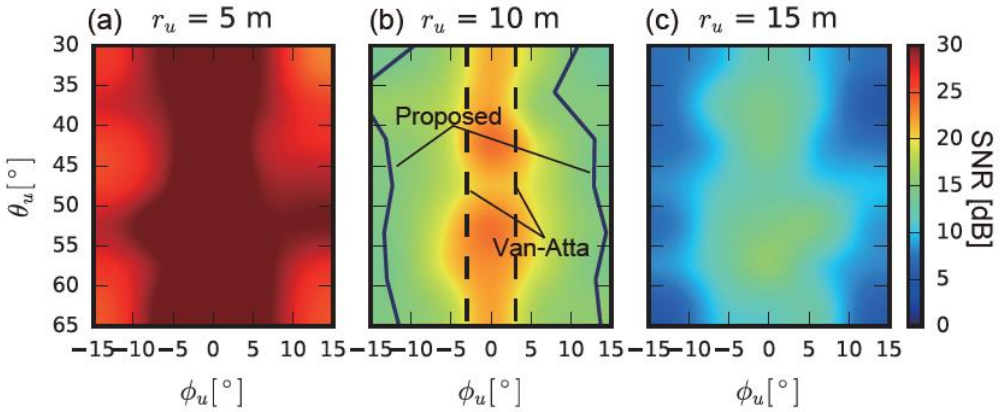
MilliSign tag



Readout test using UAV

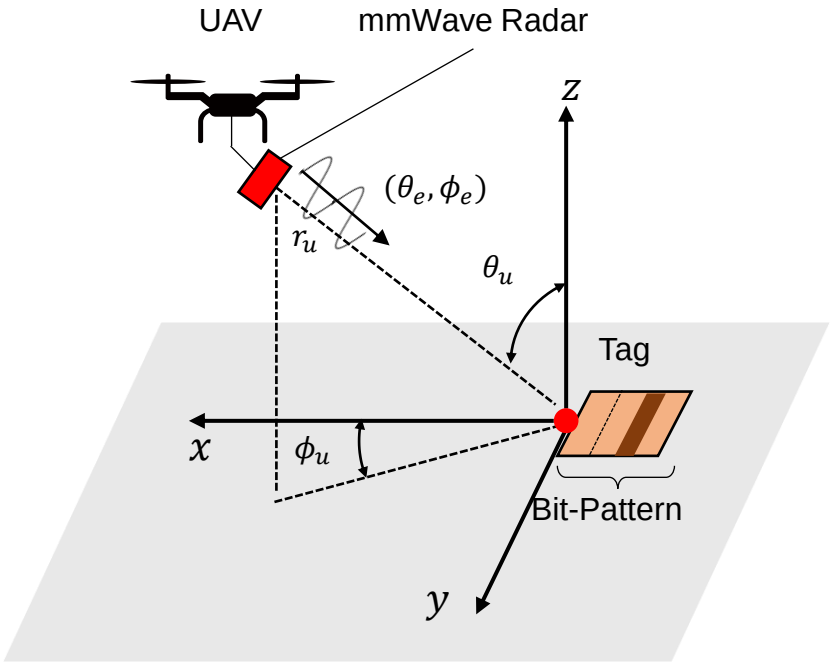
Evaluation: 3D Range vs. SNR

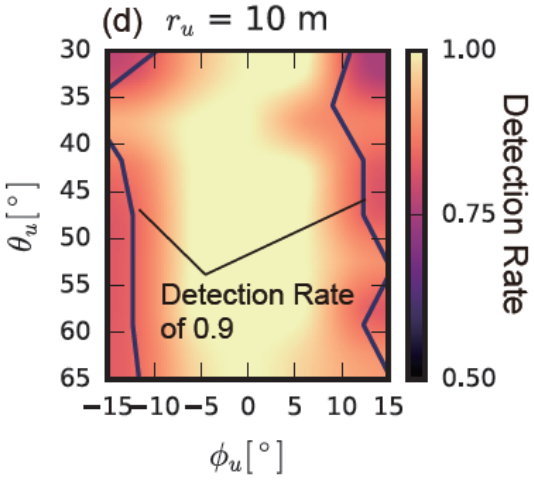


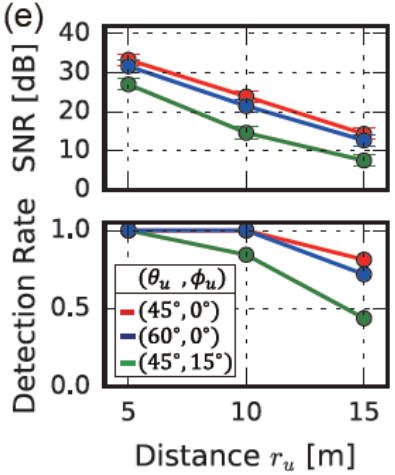


7.8 times wider coverage than Van-Atta antenna (conventional).

Evaluation: 3D Range vs. Detection Rate





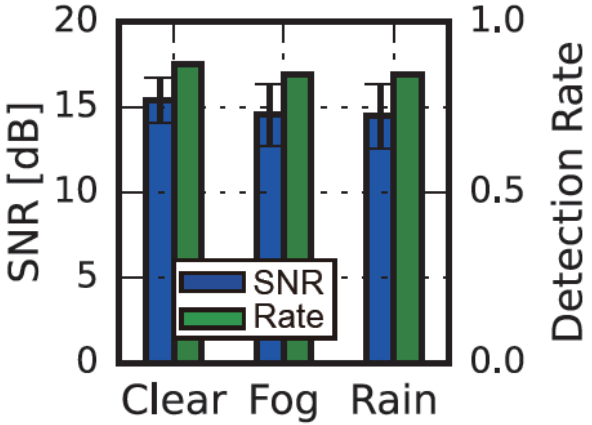


Detection rate exceeding 90% over a wide range (~10m).

Evaluation: Poor Visibility Conditions

Fog

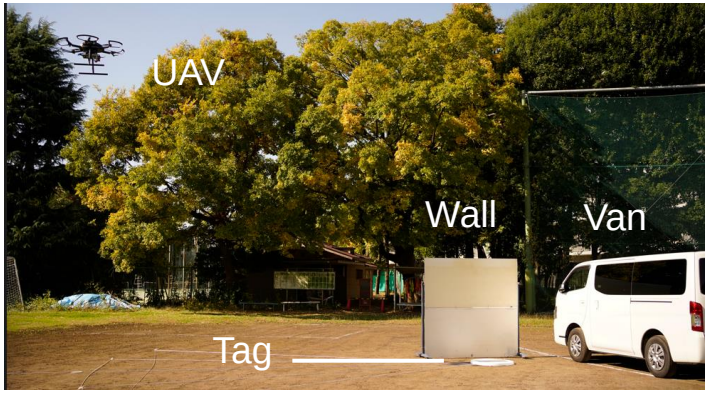
Rain

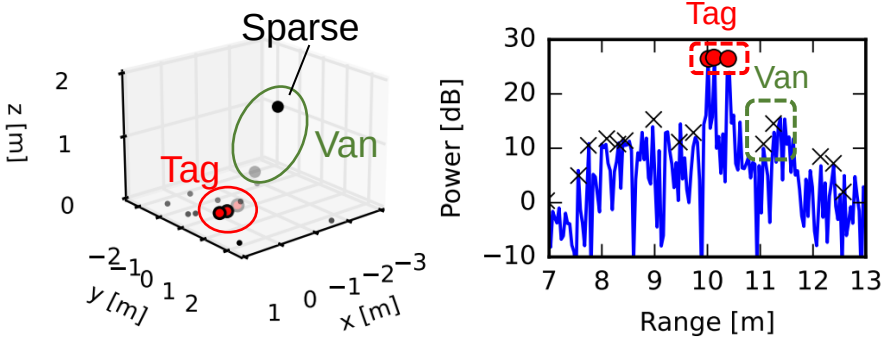


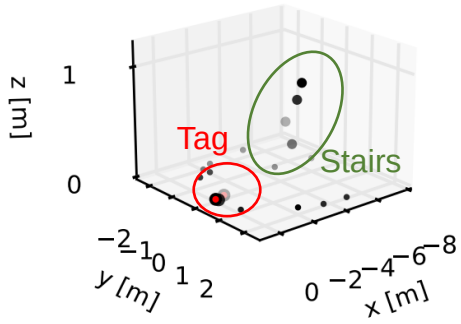
at $(r_u, \theta_u, \phi_u) = (15\ \mathrm{m}, 45°, 0°)$

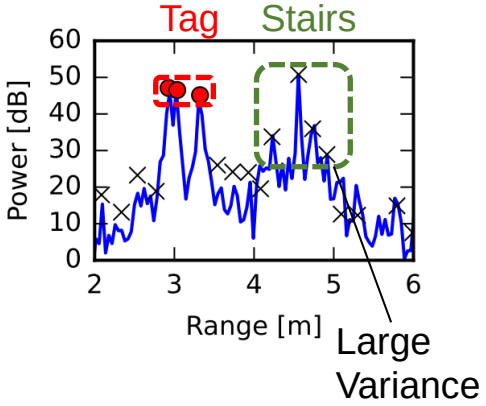
Fog and rain does not affect MilliSign

Evaluation: Multipath Rich Environment





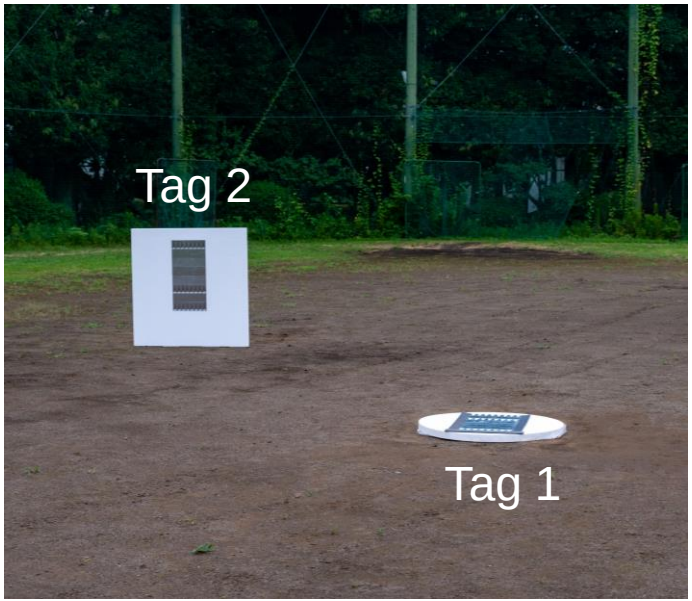




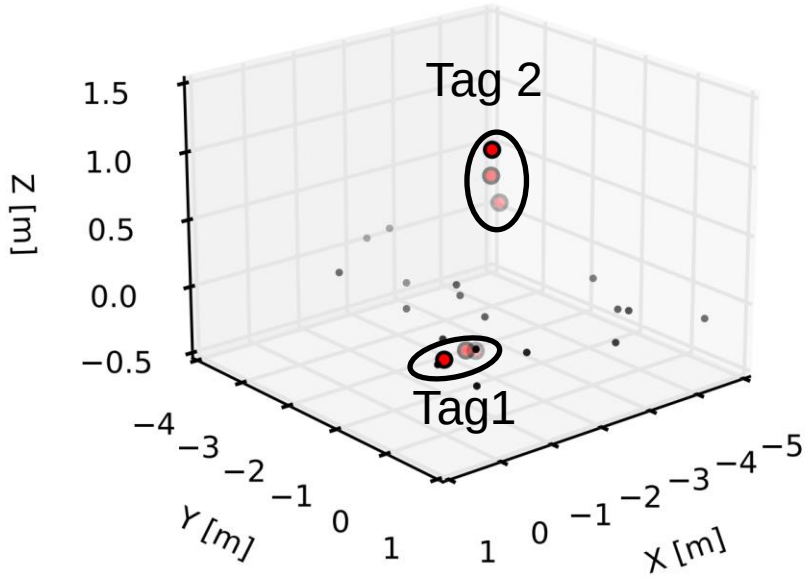
Our system can distinguish the tag from obstacles.

Evaluation: Multiple Tag Readout

Multiple tags installation



Detected bits



Our system can read out multiple tags simultaneously

Conclusion

We present Millisign, a batteryless and all-weather signage system for guiding UAVs

Our technical contributions are:

- Corner reflector-based chipless RFID tag design that achieves a wide 3D read range.
- Signal processing pipeline for accurately reading the chipless RFID tags.