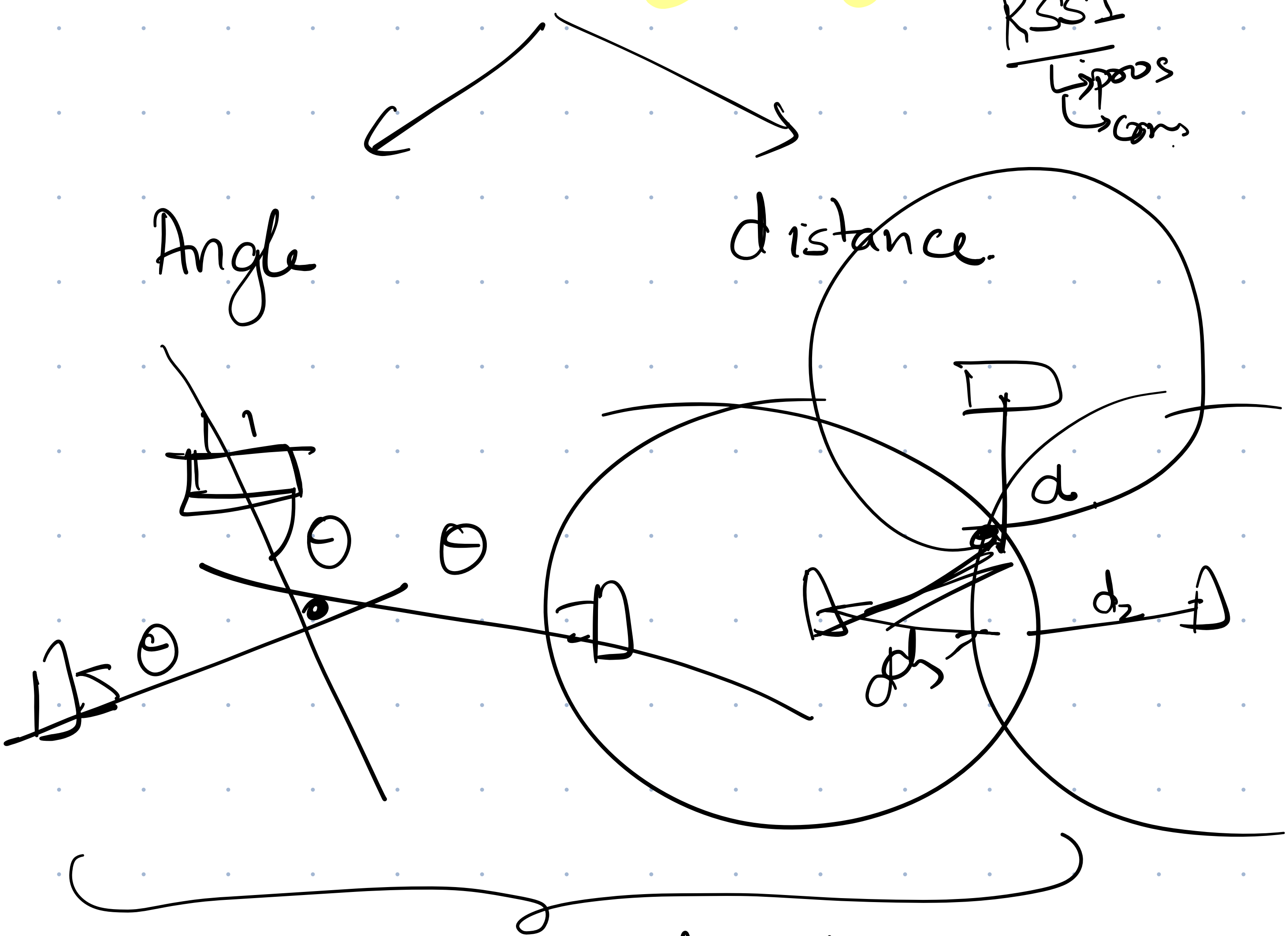
CS 598 WSI, LECTURE 11

- Estimating position
- Velocity estimation
  - Optical flow
  - Doppler Shift
- Batmobility.

Position Estimation: RF



multipath

Pros	Cons
→ non-line of sight	→ computation
→ precise indoors for	→ infrastructure (fingerprint)
	→ need to know AP location

Position Estimation: IMU

Inertial ~~motion~~
measurement unit

- **accelerometer**
  - acceleration
  - 3-dof
- Gyroscope
  - angular velocity
- **magnetometer**
  - magnetic field
  - ⇓ global orientation

0.01 m/s^2 acceleration $\int \rightarrow$ velocity (0.01 m/s) $\int \rightarrow$ distance (1m). (relative location)

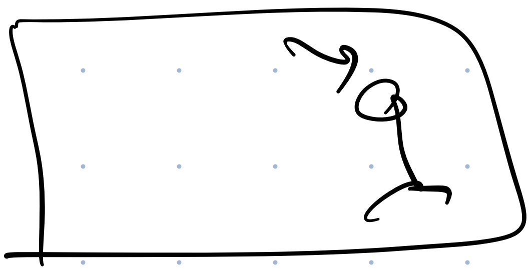
Gyroscope angular velocity: 0.1 m/s

Pros	Cons
→ cheap	→ suffer from drift.
→ l	→ relative location only.

computation higher ~~higher~~ s
higher sampling

Vision-based Positioning

- Cameras
  - → localize
- LIDARs



Pros	Cons
→ cameras are useful for multiple applications	→ Low light or occlusions.
→ robust ecosystem for detection & track.	→ non-line of sight
	→ depth is non trivial with a single camera
	→ more computation.

Estimating Velocity

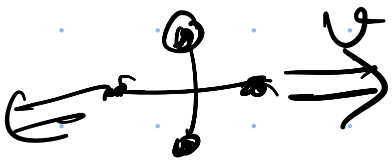
position → derivative of position over time.

velocity can be "easier"

↓

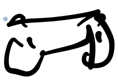
accelerometer → single integration of acceleration

relative motion.



v target velocity = $v \approx 0$

observed velocity = ~~v'~~



$v' \simeq v$

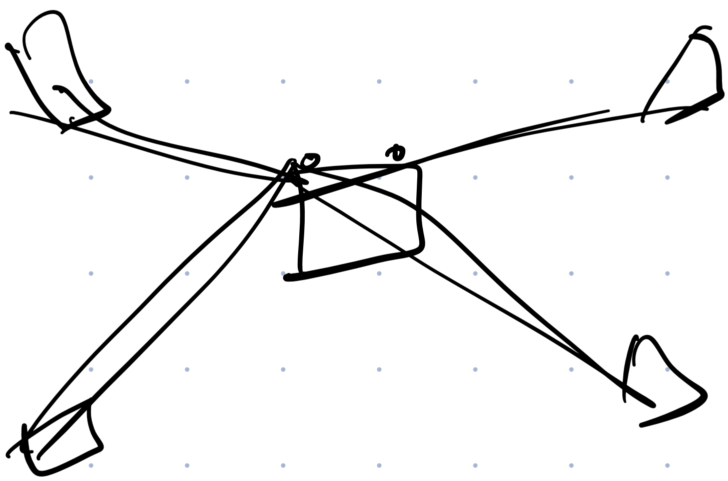
outside-in vs. inside out

Infrastructure-driven

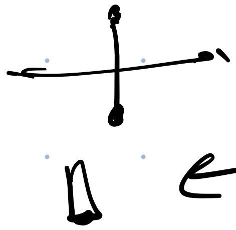
IR (infrared)-based systems

Sensors on the drone.

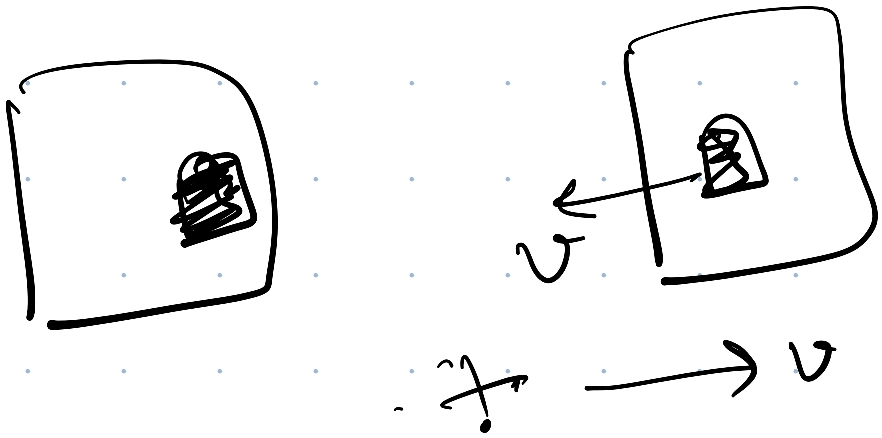
IMU on the drone.



Optical Flow



← down facing camera.



Challenges

- → dark / bad lighting conditions
- → featureless
- → privacy - challenges

⇓

Radar to provide velocity-based control.

Doppler Shift

RF signals → frequency f.

observed freq. = $f + \frac{vf}{c}$

⇓ doppler shift

freq. of the reflections

$0.5\,Hz = \frac{vf}{c} = \frac{60 \times 10^{9}}{3 \times 10^{8}}$ (20, 10)

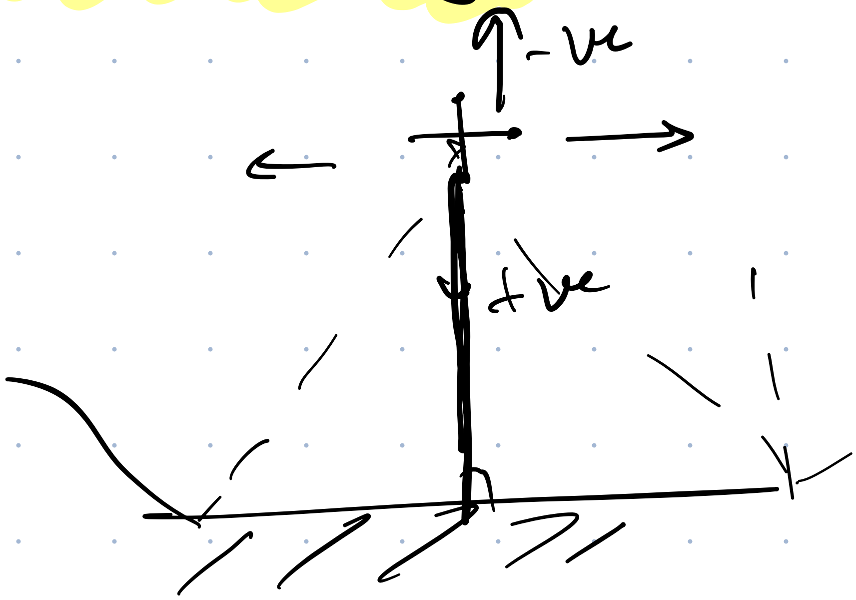
⇓

velocity > speed limit.

$V_2 = \frac{1}{2} = v \times 200$

$v = \frac{1}{400}$ m/s

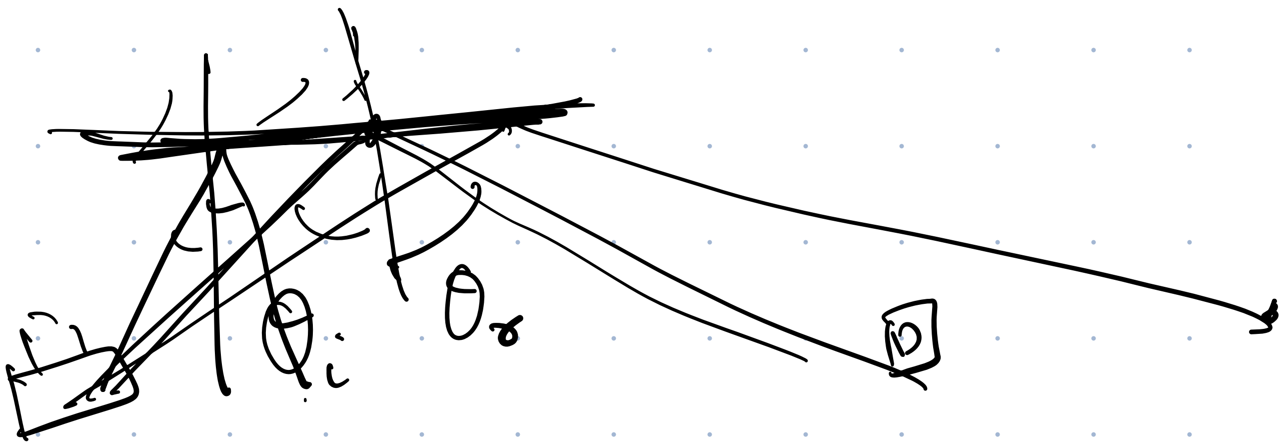
BatMobility



doppler shift is supposed to be zero

surface-parallel doppler shift.

dispersion vs. reflection.



~~is the~~ mu much smaller than wavelength

⇓

smooth surface.

of the same order as wavelength

⇓

rough surface.

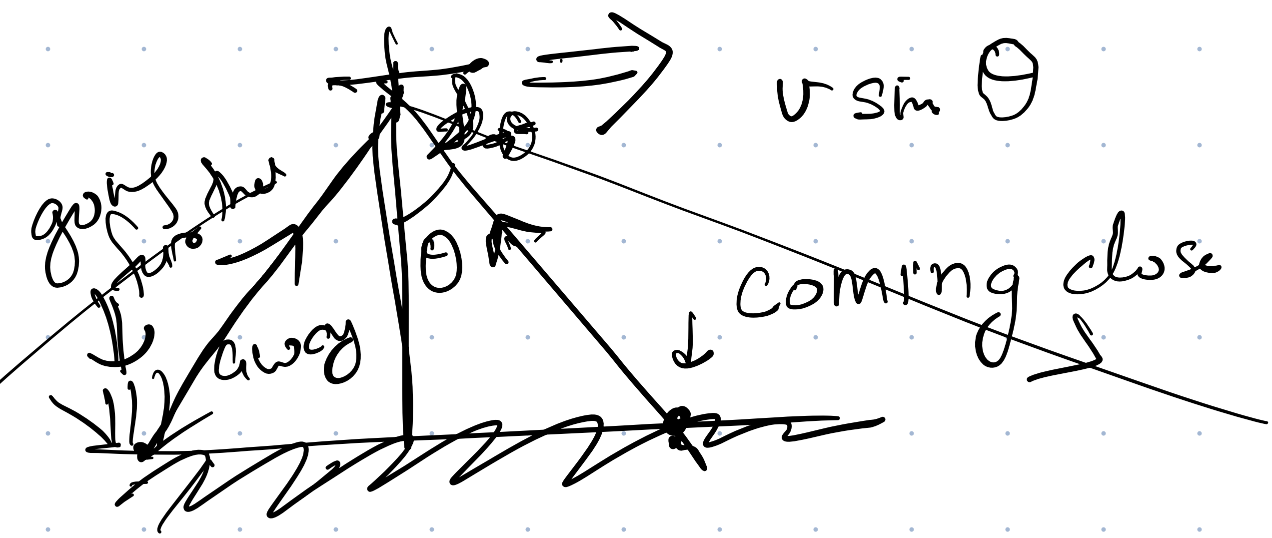
light is dispersive

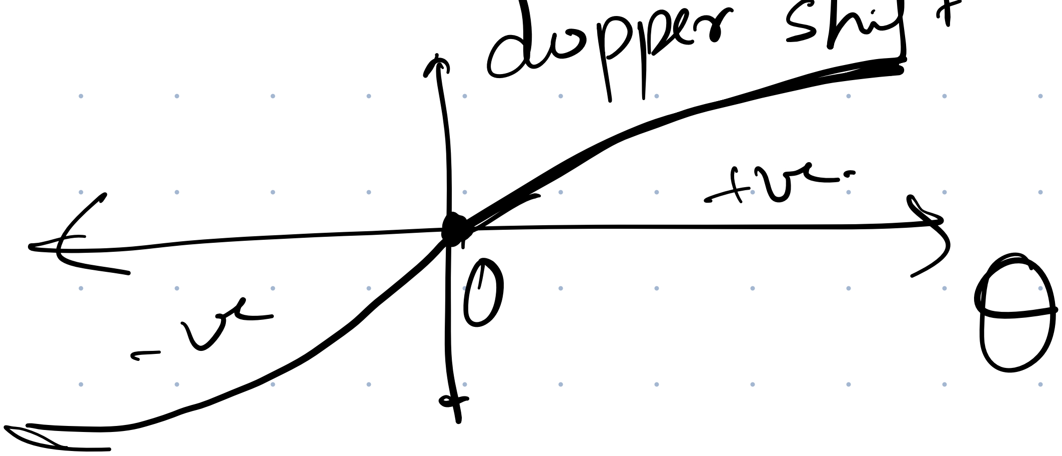
Wi-Fi → 6 – 12cm

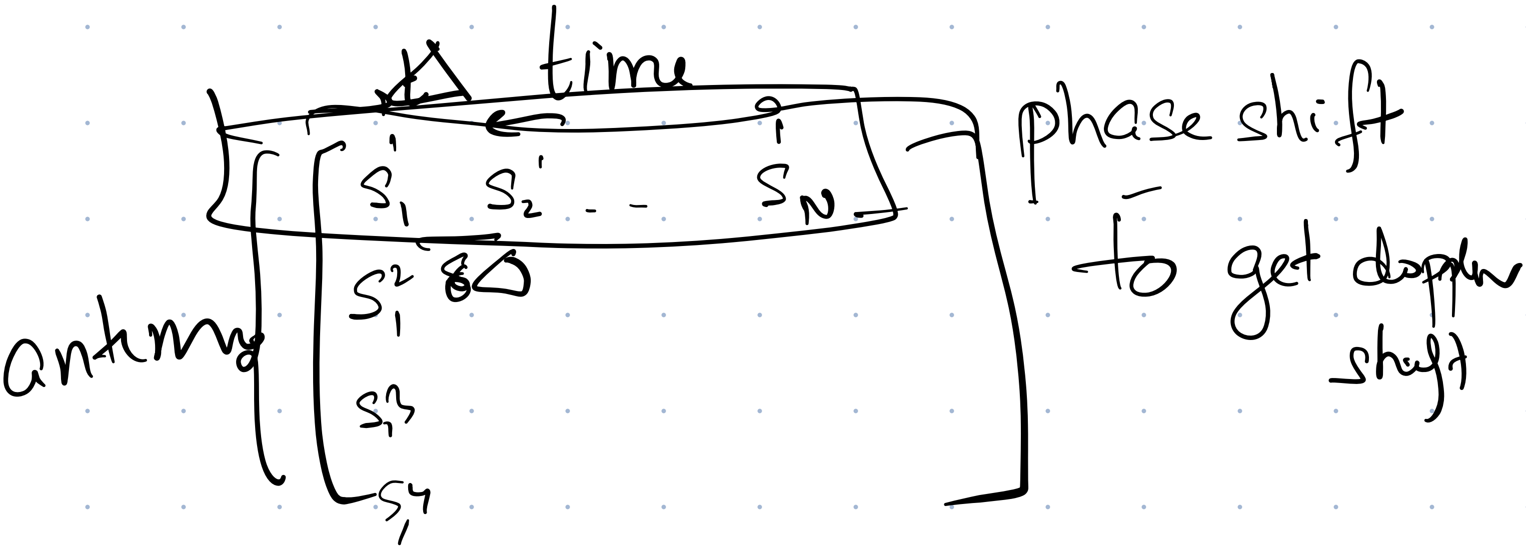
mmWave frequencies → < 1cm

few mm.

floor is dispersive







δ

$$S_2^1 = S_1^1 e^{j2\pi\delta\Delta \times 3}$$

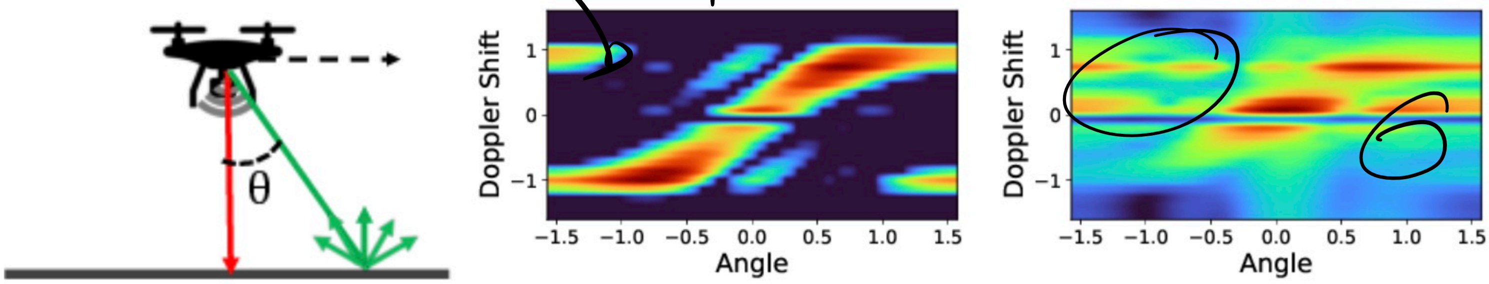
maximum velocity → Δ

minimum velocity detected ⇒ how much time do you capture?

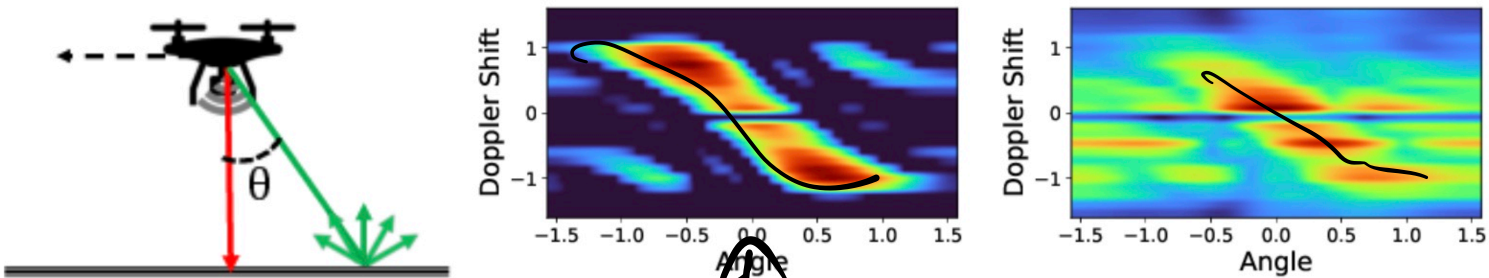
doppler shift res $\propto \frac{1}{T}$ = consider for computed

2 s = 0.5 Hz

Shape → direction of motion



(a) (left) Motion of the UAV, (center) Simulated doppler-angle plot, (right) Observed doppler-angle plot.



(b) (left) Motion of the UAV, (center) Simulated doppler-angle plot, (right) Observed doppler-angle plot.

amplitude → (velocity)

→ multipath
→ limited resolution
→ ground may not be flat

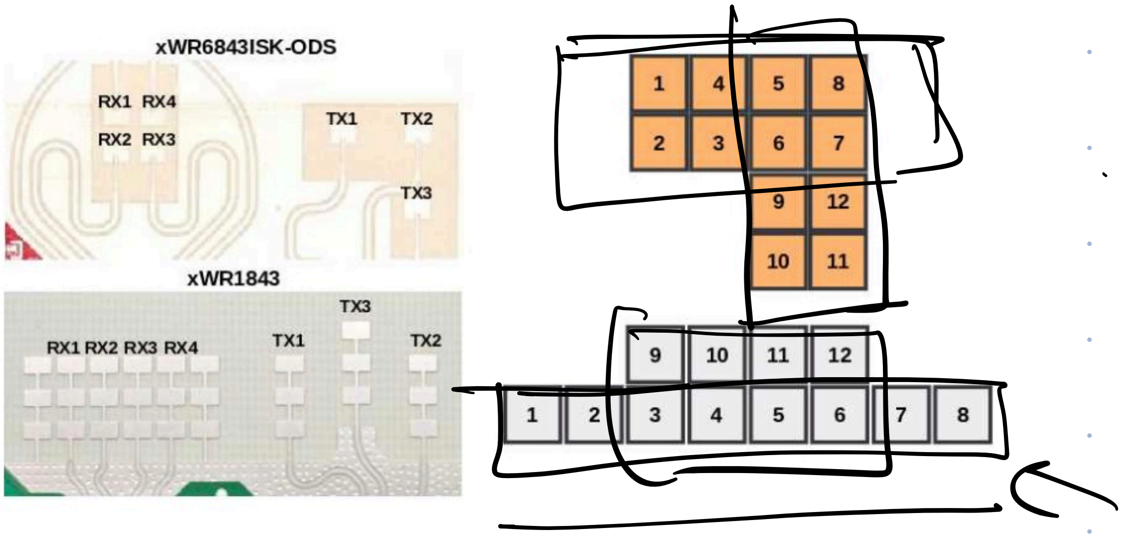
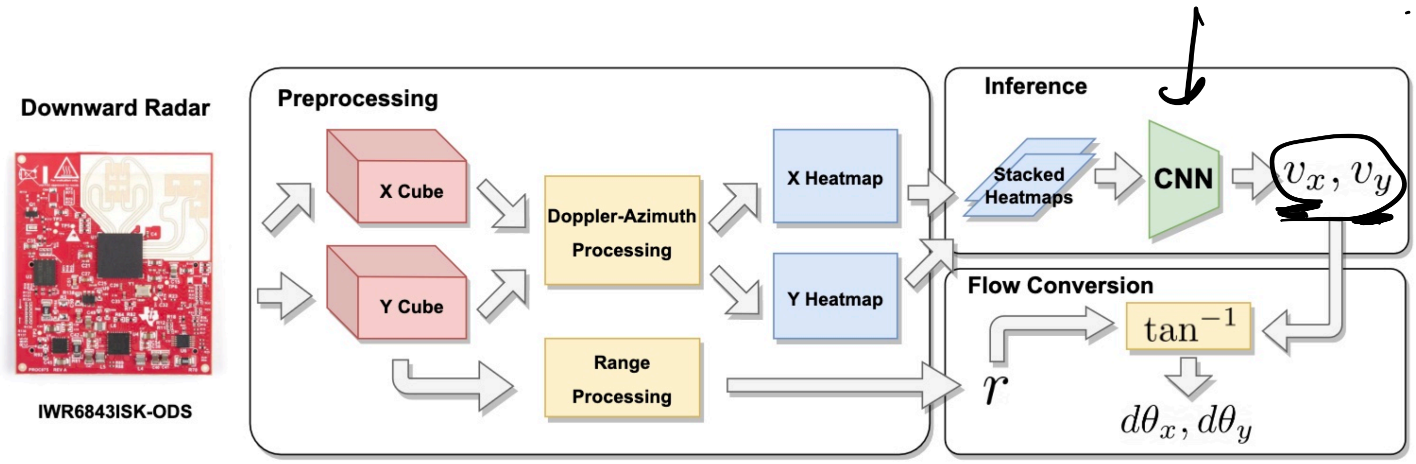
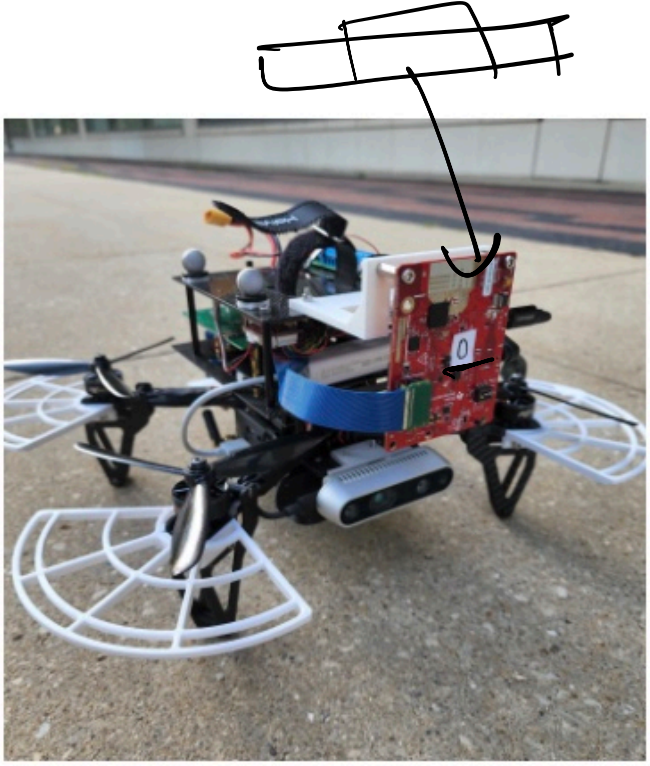
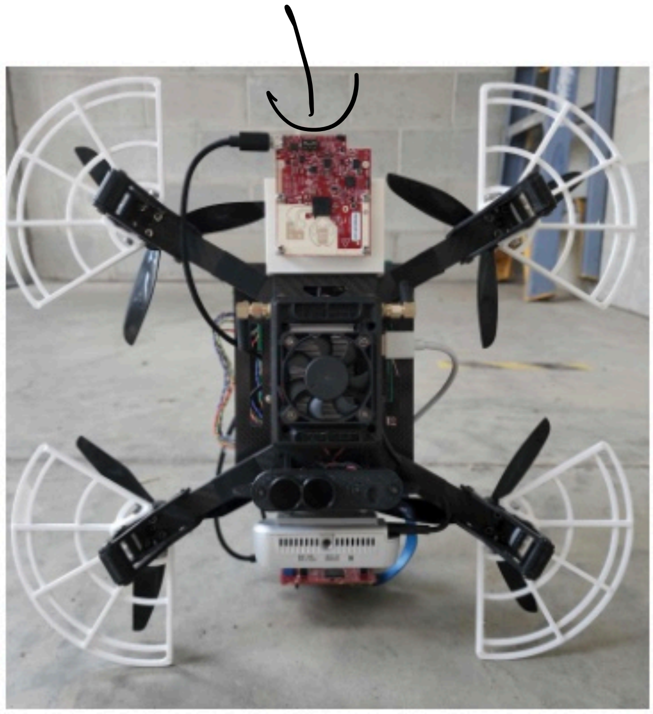


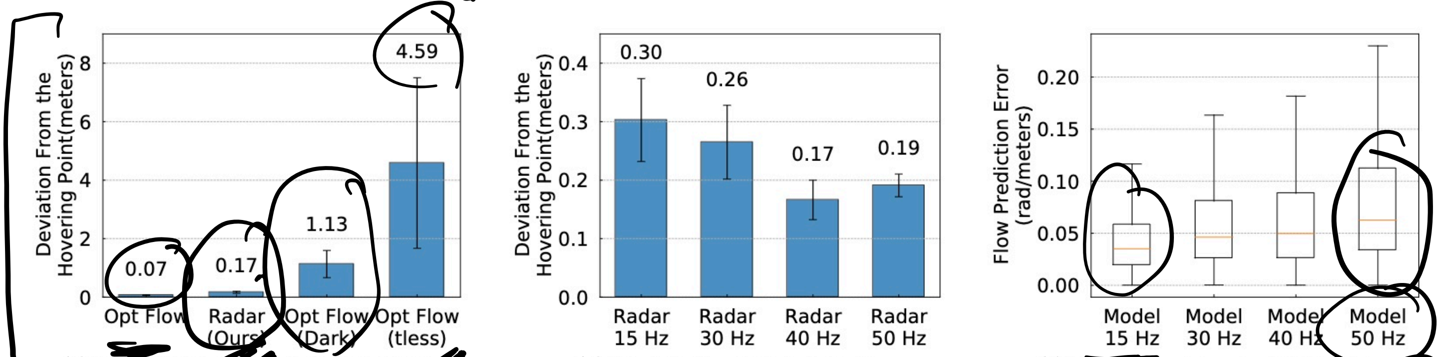
Figure 5: *Left.* Physical antenna array layouts on single-chip mmWave radar boards. *Right.* Corresponding numbered virtual antenna array under TDM MIMO.



Downward Radar
IWR6843ISK-ODS
Preprocessing
X Cube
Y Cube
Doppler-Azimuth Processing
Range Processing
X Heatmap
Y Heatmap
Inference
Stacked Heatmaps
CNN
v_x, v_y
Flow Conversion
r
$\tan^{-1}$
$d\theta_x, d\theta_y$







(a) Median Deviation from Position (b) Deviation vs Update Rate (c) Flow accuracy vs update rate

Figure 13: Loiter Test. (a) UAV equipped with BatMobility holds its position, but optical flow fails in dark and textureless conditions. (b) Higher update rates support better hovering performance, in spite of higher flow prediction errors shown in (c).