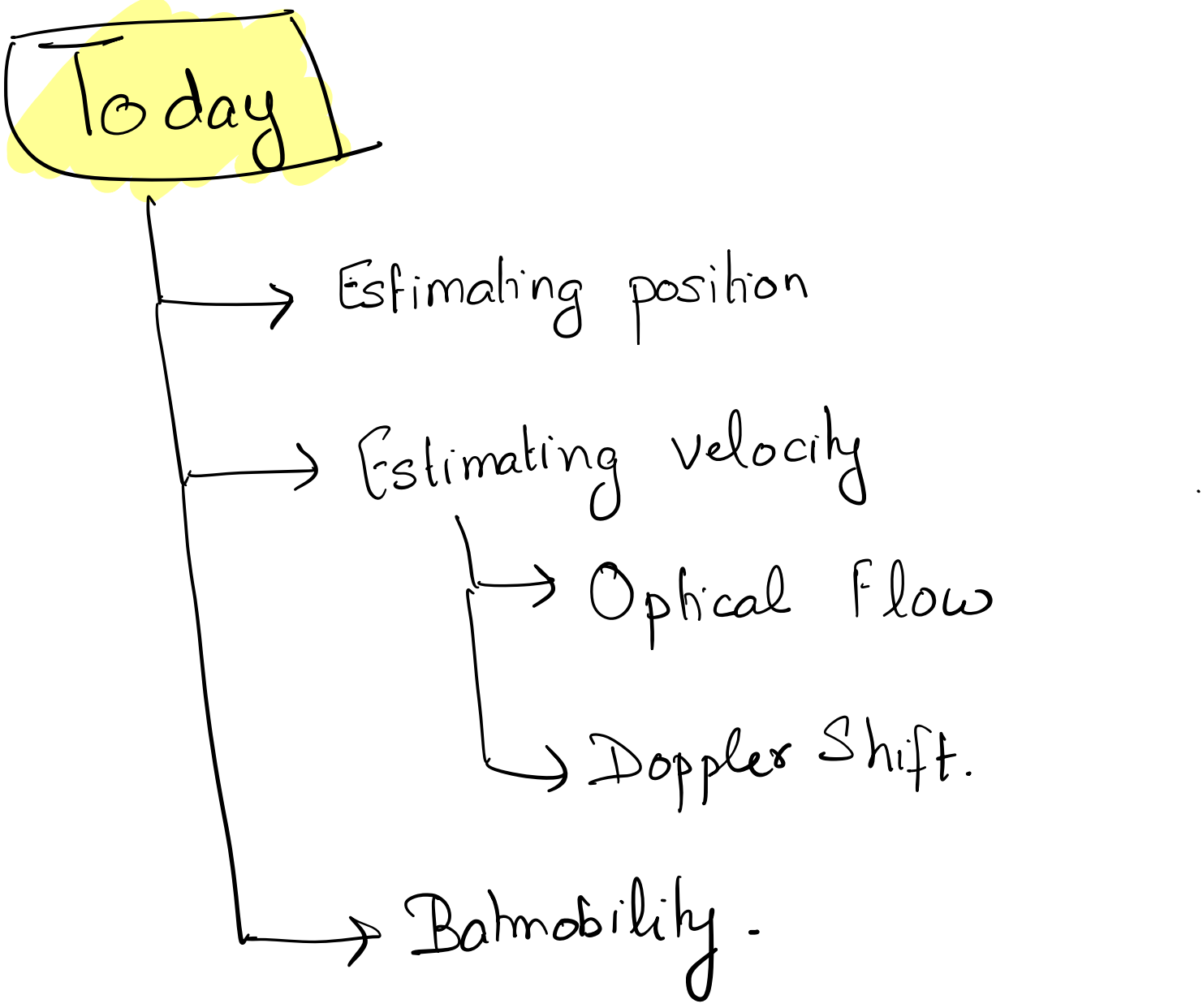

Today
Estimating position
Estimating velocity
Optical Flow
Doppler Shift.
Batmobility.

Position Estimation

→ Distance / AoA "outside-in"

fast ↔ infrastructure.

Vision-based

→ IR trackers.

→ IMU → Inertial Measurements Motion Unit

→ Accelerometer

→ Gyroscope → angular velocity

→ Magnetometer

→ acceleration → velocity → distance

integrate integrate

0.1 m/s → 0.1

0.2

0.3 . . .

drift.

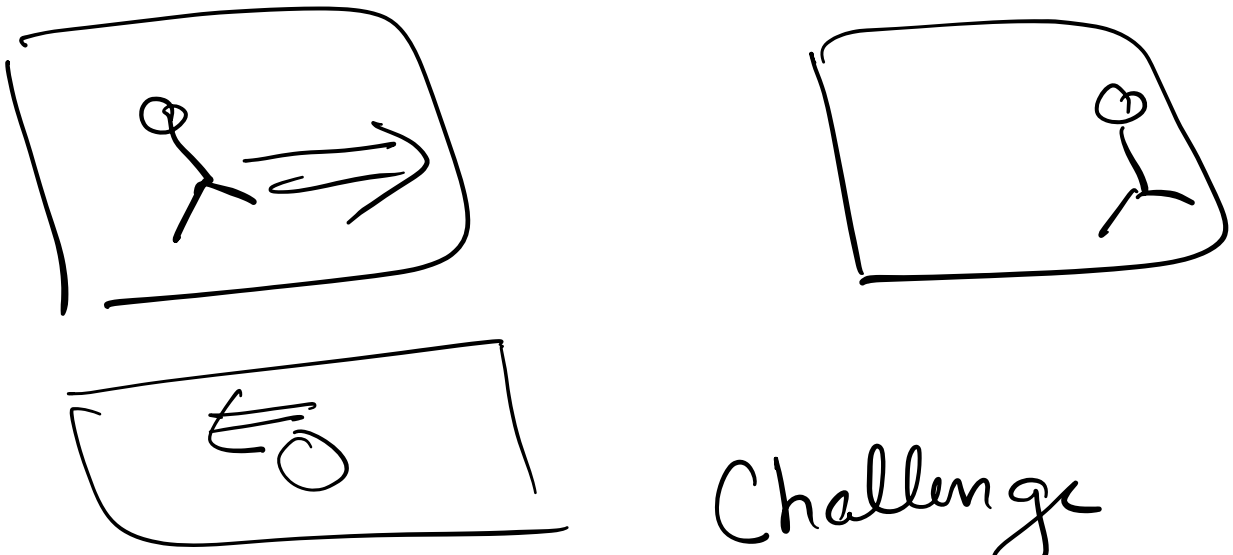
Vision-based Sensors

Camera

LIDAR.

↳ precise position

Structure from motion.



Challenge

↳ privacy.

↳ {lighting conditions}

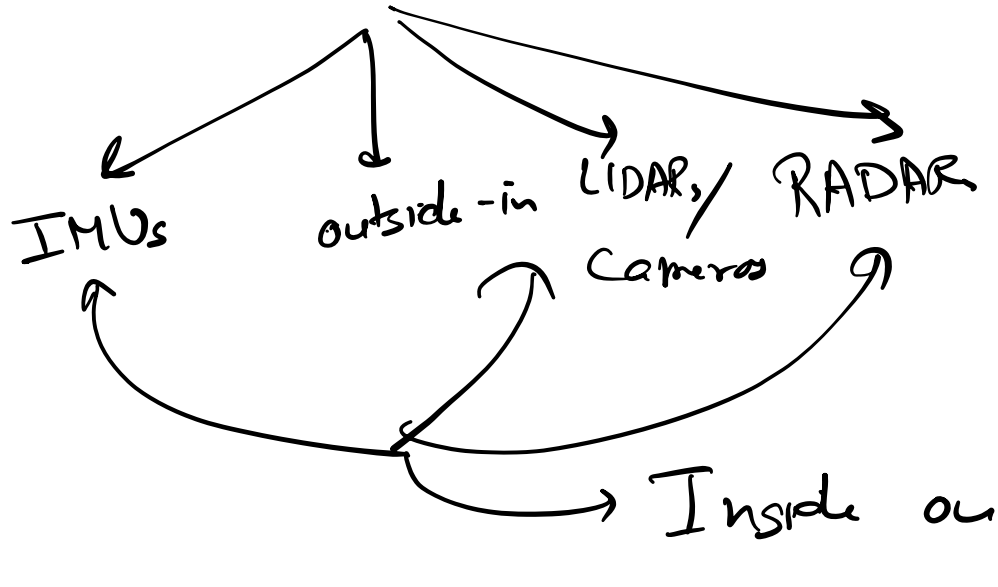
↳ occlusions.

Radar

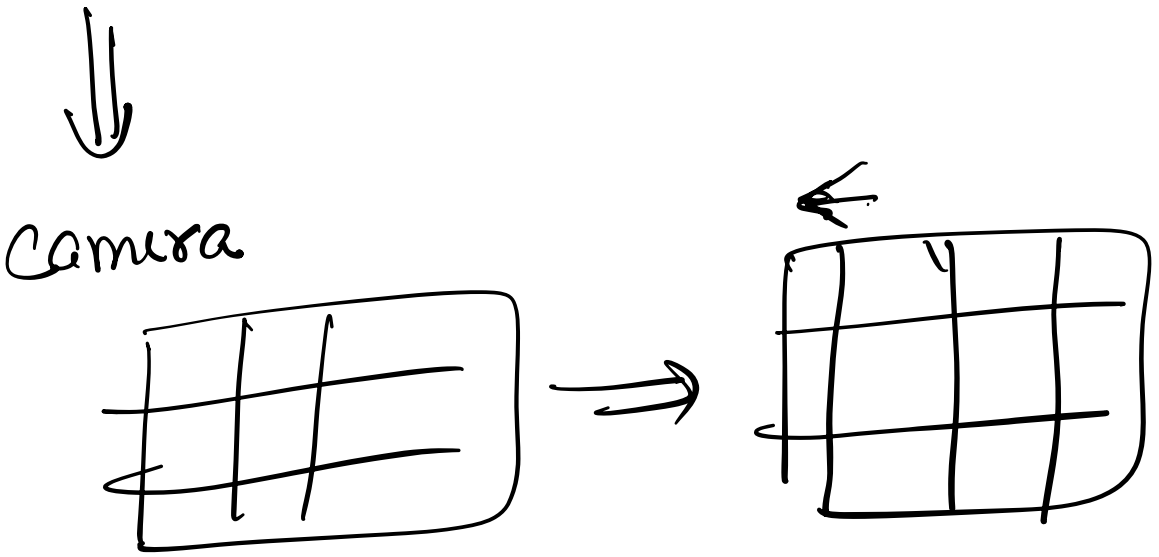
Estimating Velocity

↳ V_x, V_y, V_z

drone / robot ← stay static → 0, δ, −δ



Optical Flow



camera → optical flow ⇒ estimate velocity

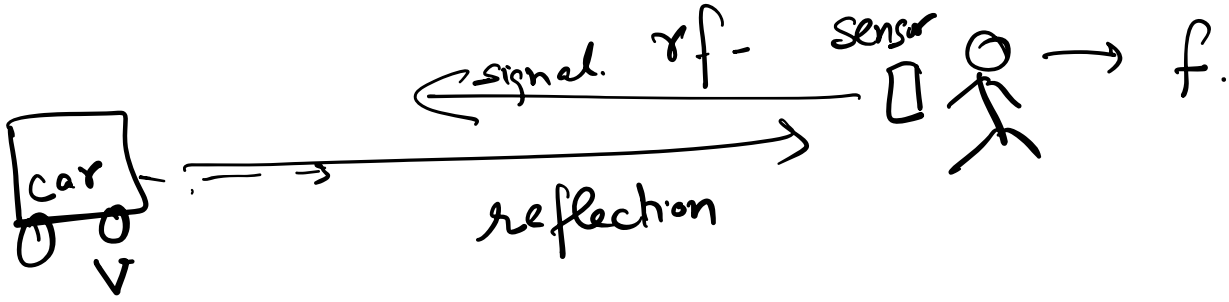
⇓

Compare to expected output ⇐ apply the opposite to the difference.

- occlusion
- bad lighting condition dirt/grime
- textureless surfaces.

Doppler Shift

↳ estimate velocity.



doppler shift = $\Rightarrow \frac{v}{c} f$

$$\left(f + \frac{v}{c} f \right)$$

v → velocity

f → frequency of the signal.

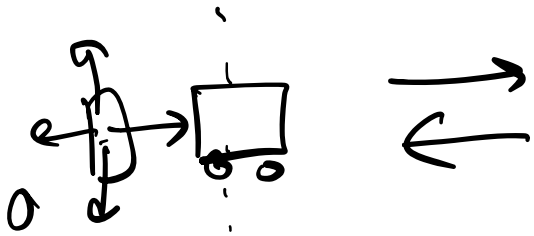
c → speed of the wave

$$f' = f + \frac{v}{c} f$$

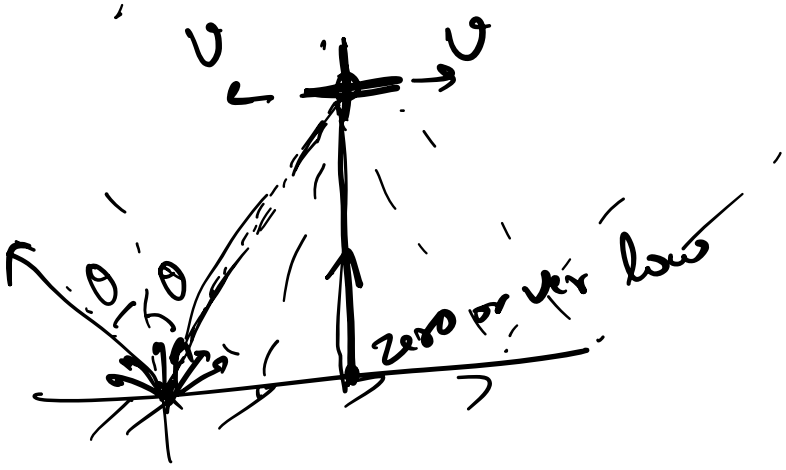
Batmobility

Surface Parallel Doppler Shift

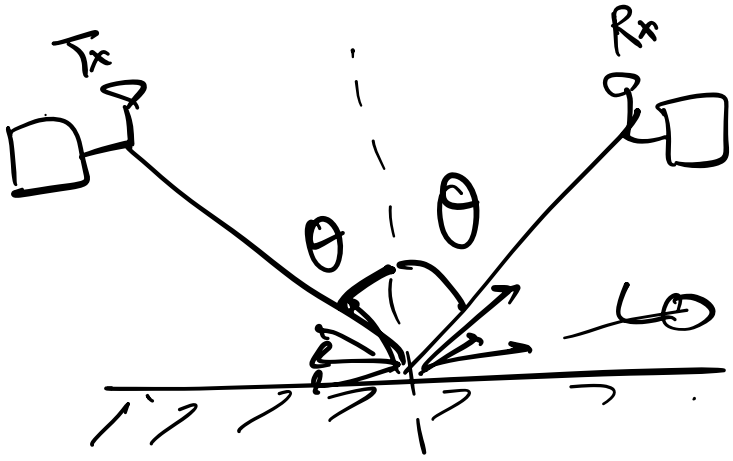
$$f' = \left[f + \frac{v}{c} f \right]$$



→ doppler shift of zero.



Reflections



Diffraction or dispersion

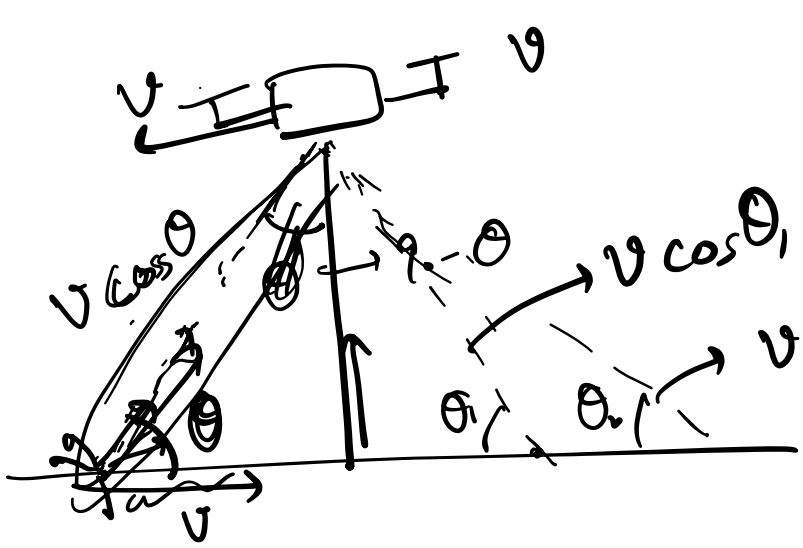
rough surfaces ≈ wavelength of wave.

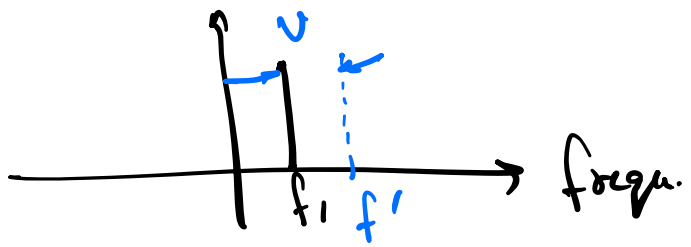
matters if

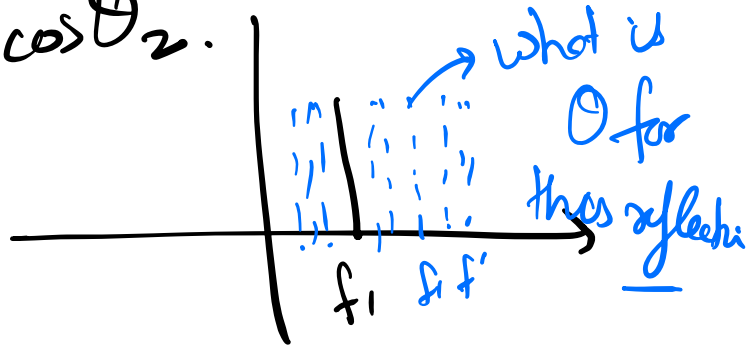
of the same order as wavelength.

Wi-Fi → 6 cm

mmWave → 70/80 GHz → wavelength. < 1 cm



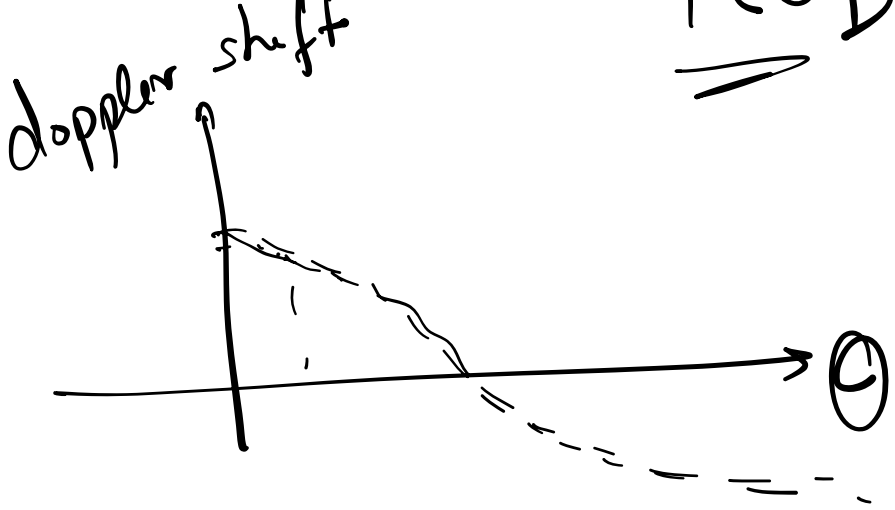


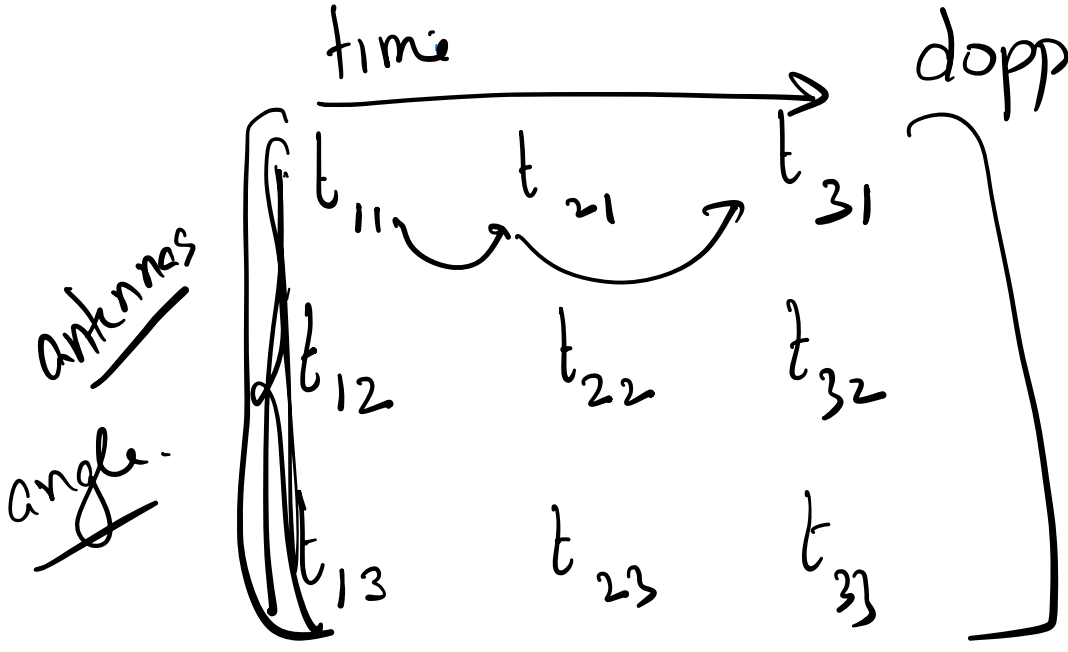


Angle of arrival

$P(\theta_1) \Rightarrow$ doppler shift

$v \cos\theta$



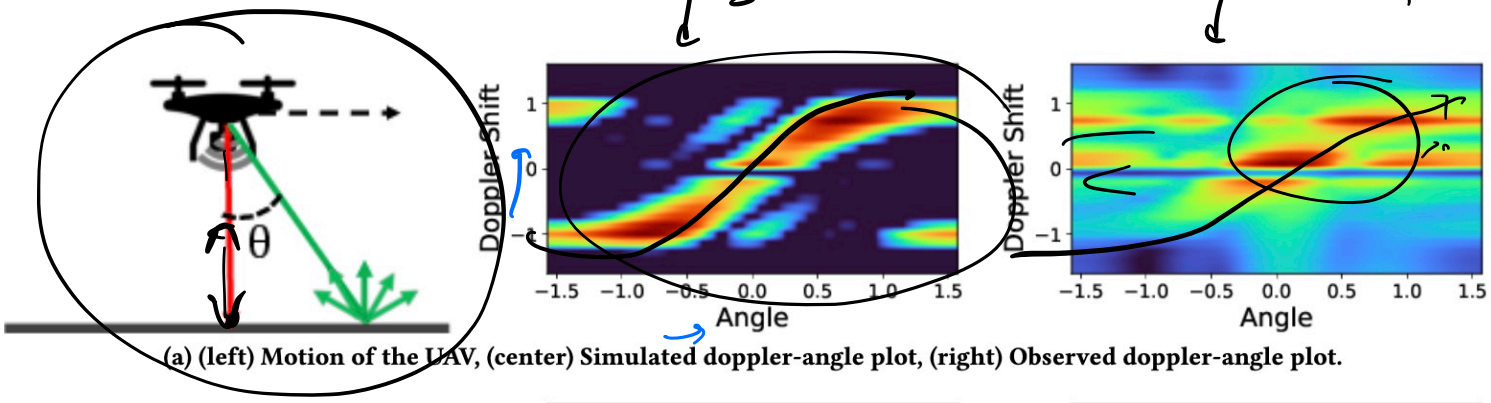


$$P(\theta_1) = \sum_i t_i$$

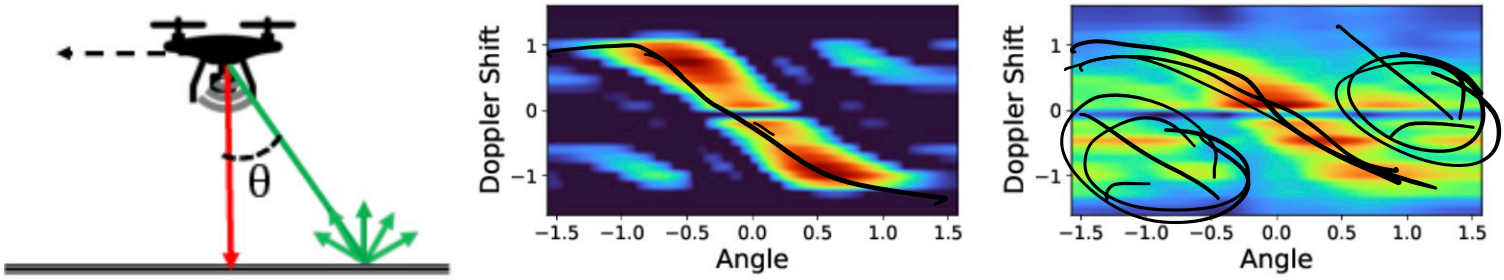
$$P(\theta_1, t_1) = \sum_i t_{1i}\, e^{j\frac{2\pi}{\lambda} i \cos\theta_1}$$

$$[P(\theta_1, t_1) \quad P(\theta_2, t_2) \quad P(\theta_1, t_3)]$$

doppler shift



(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.

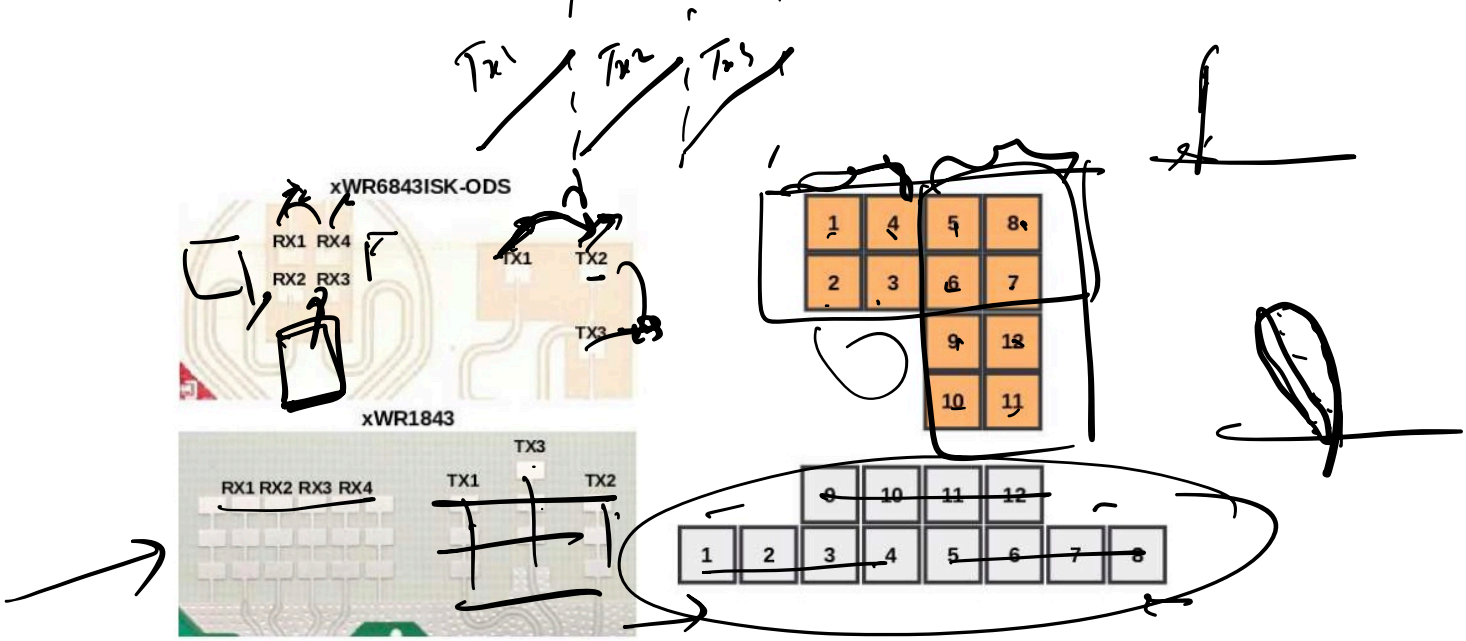
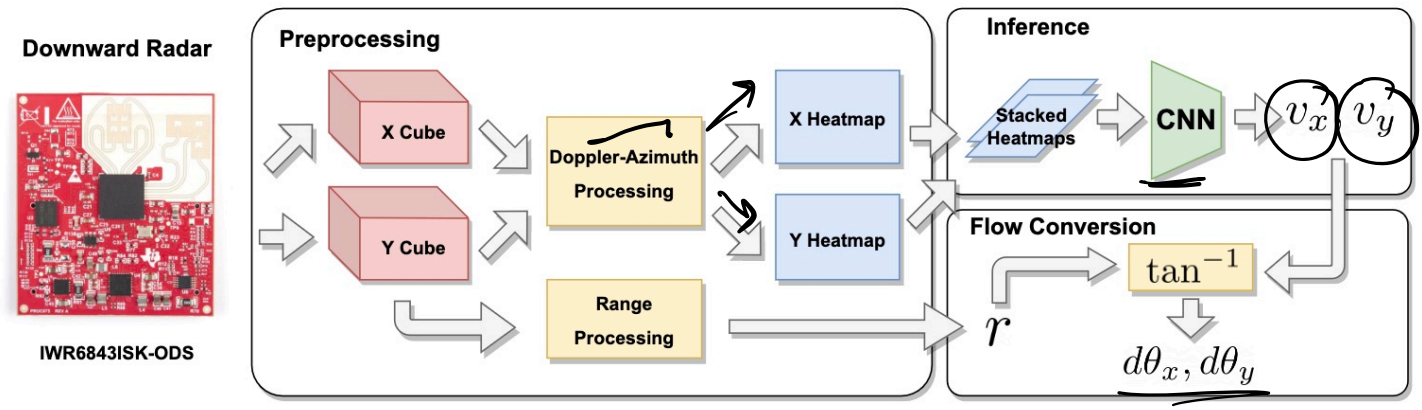
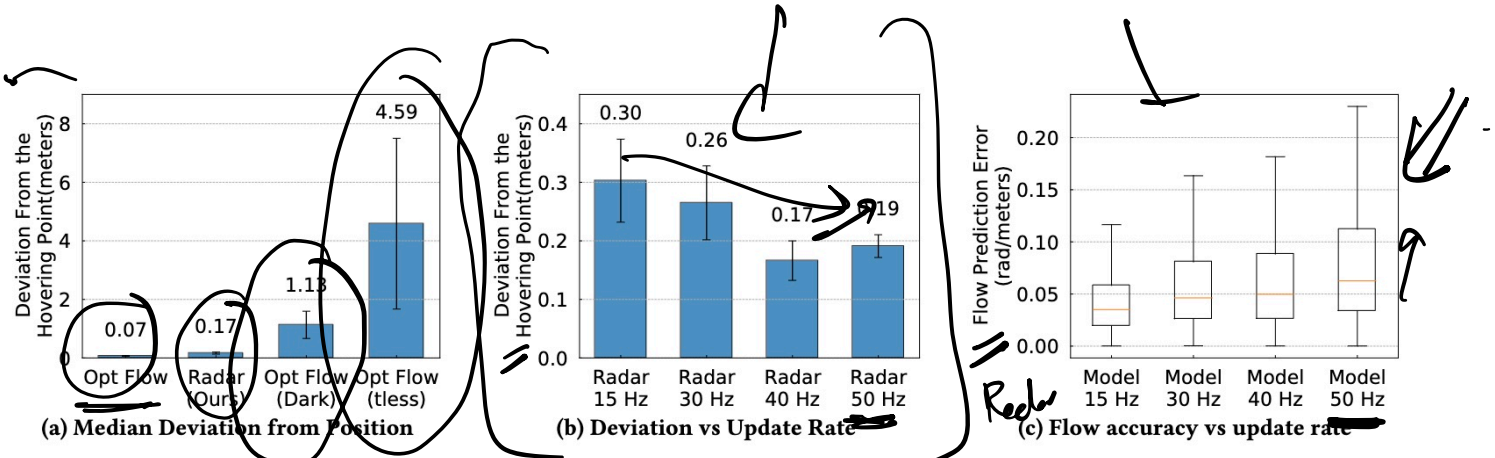


Figure 5: ***Left.*** **Physical antenna array layouts on single-chip mmWave radar boards.** ***Right.*** **Corresponding numbered virtual antenna array under TDM MIMO.**


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
$\tan^{-1}$
r
$d\theta_x, d\theta_y$



(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).