BatDeck: Advancing Nano-drone Navigation with Low-power Ultrasound-based Obstacle Avoidance

Hanna Müller*, Victor Kartsch*, Michele Magno*, Luca Benini*†
*D-ITET – ETH Zürich, †DEI – University of Bologna,

Why Nano-UAVs?

- Agile
- Safe around humans
- Affordable

[1]

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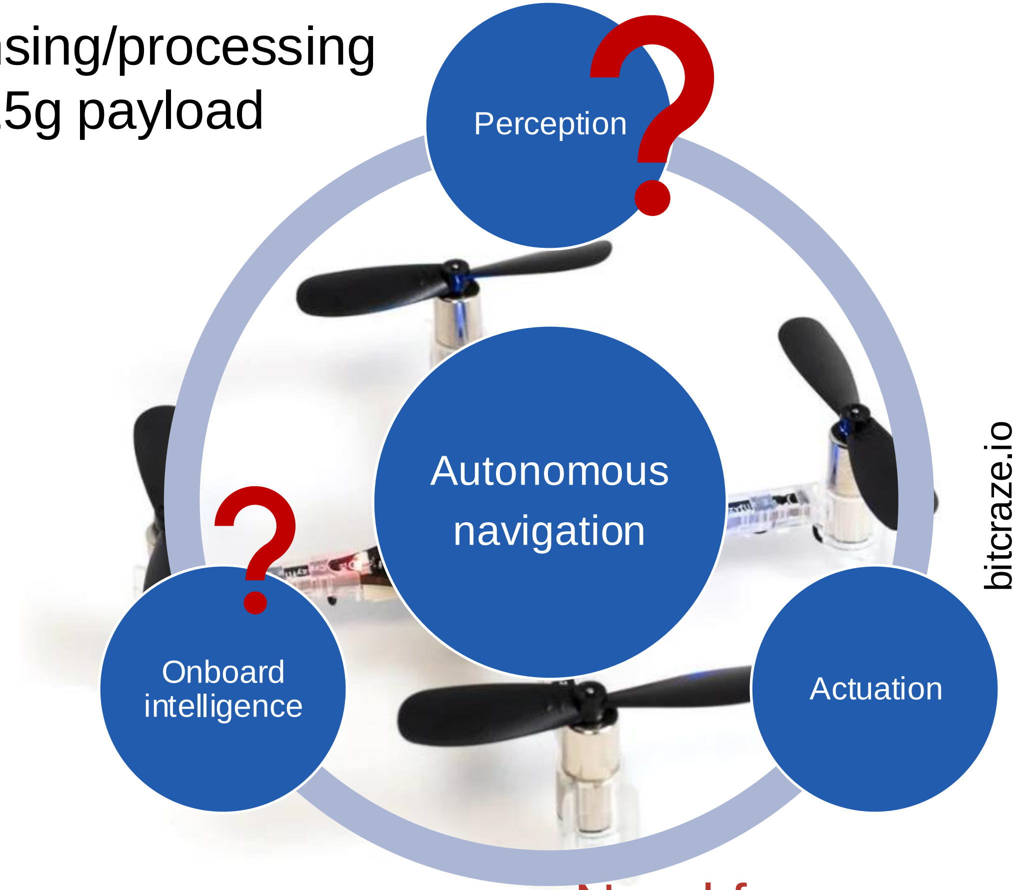
Challenges

- ~1W sensing/processing
- ~30g + 15g payload



Need for
low-power, lightweight sensors
and processing!

[1] D. Falanga, K. Kleber, S. Mintchev, D. Floreano, D. Scaramuzza, "The Foldable Drone: A Morphing Quadrotor that can Squeeze and Fly". IEEE Robotics and Automation Letters (RA-L), 2018.

How to Perceive Obstacles on Nano-UAVs

[1] 

[2] 

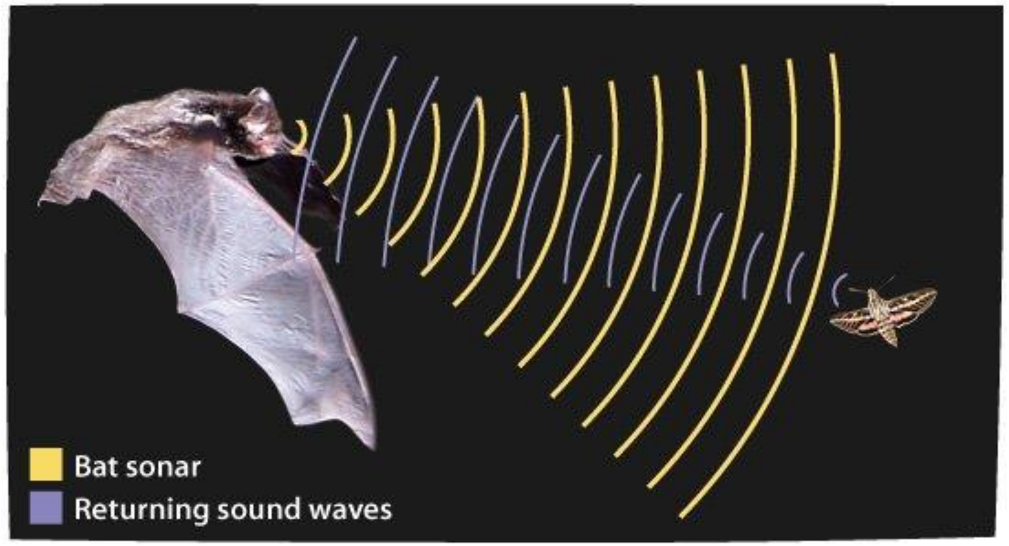
Technology	FoV	Max range (on a flying drone)	Frequency	Power	Limitations
940nm invisible laser-based (VCSEL)	27°	<3m	60Hz	~45mW	Light absorbing/reflecting obstacles (glass, metal)
HM01b0 camera	64° (diag.)	Light dependent, several meters	~60Hz	~2mW	Light dependent, High computational load

[1] Kimberly McGuire et al. (2019). Minimal navigation solution for a swarm of tiny flying robots to explore an unknown environment. Science Robotics.

[2] Daniele Palossi et al. (2019). A 64-mW DNN-Based Visual Navigation Engine for Autonomous Nano-Drones. *IEEE Internet of Things Journal*

Are there animals that can fly in all light conditions?

How Bats See the World



- Emit/receive 9 kHz to 200 kHz ultrasound waves
- Frequency modulated (FM) or constant frequency (CF) ultrasonic waves

- [1] used audible sound
- Sensible to noise

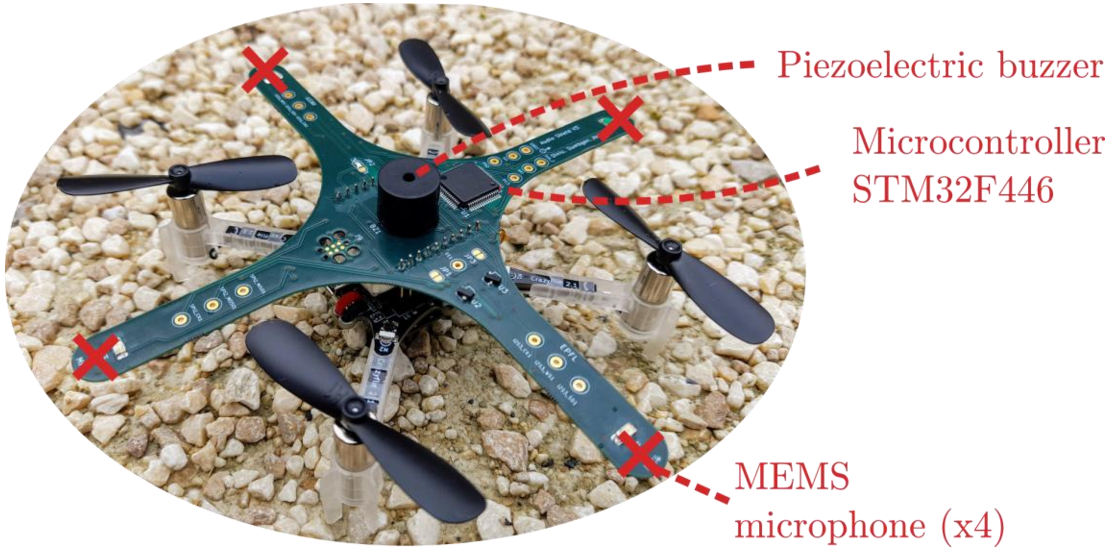
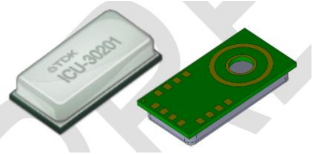


Image: https://askabiologist.asu.edu/echolocation

[1] F. Dümbgen, A. Hoffet, M. Kolundžija, A. Scholefield, and M. Vetterli, "Blind as a bat: audible echolocation on small robots", IEEE Robotics and Automation Letters (Early Access), 2022.

Low-power Sensors for Obstacle Avoidance

?



[1]

[2]

Technology	FoV	Max range (on a flying drone)	Frequency	Power	Limitations
50kHz ultrasonic waves	55°	<2.5m	~33Hz	~500µW	Sound absorbing obstacles (fabric, plants)
940nm invisible laser-based (VCSEL)	27°	<3m	60Hz	~45mW	Light absorbing/reflecting obstacles (glass, metal)
Greyscale camera	64° (diag.)	Light dependent, several meters	~60Hz	~2mW	Light dependent, High computational load

[1] Kimberly McGuire et al. (2019). Minimal navigation solution for a swarm of tiny flying robots to explore an unknown environment. Science Robotics.

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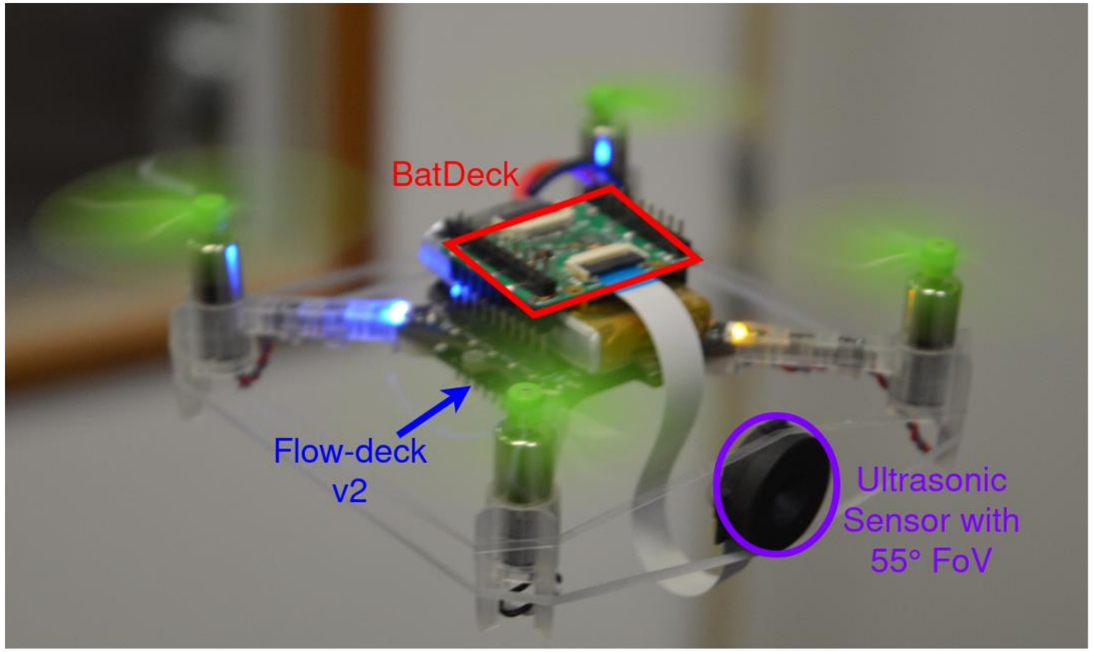
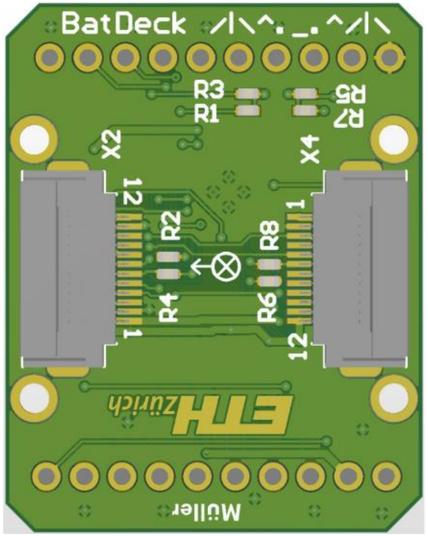
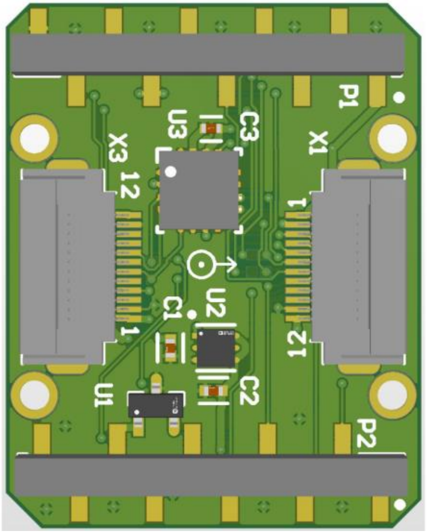
Nano-drone and BatDeck

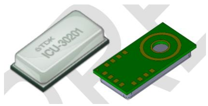






Crazyflie 2.1
STM32F405
- 168 MHz
- 70% idle next to flight controller

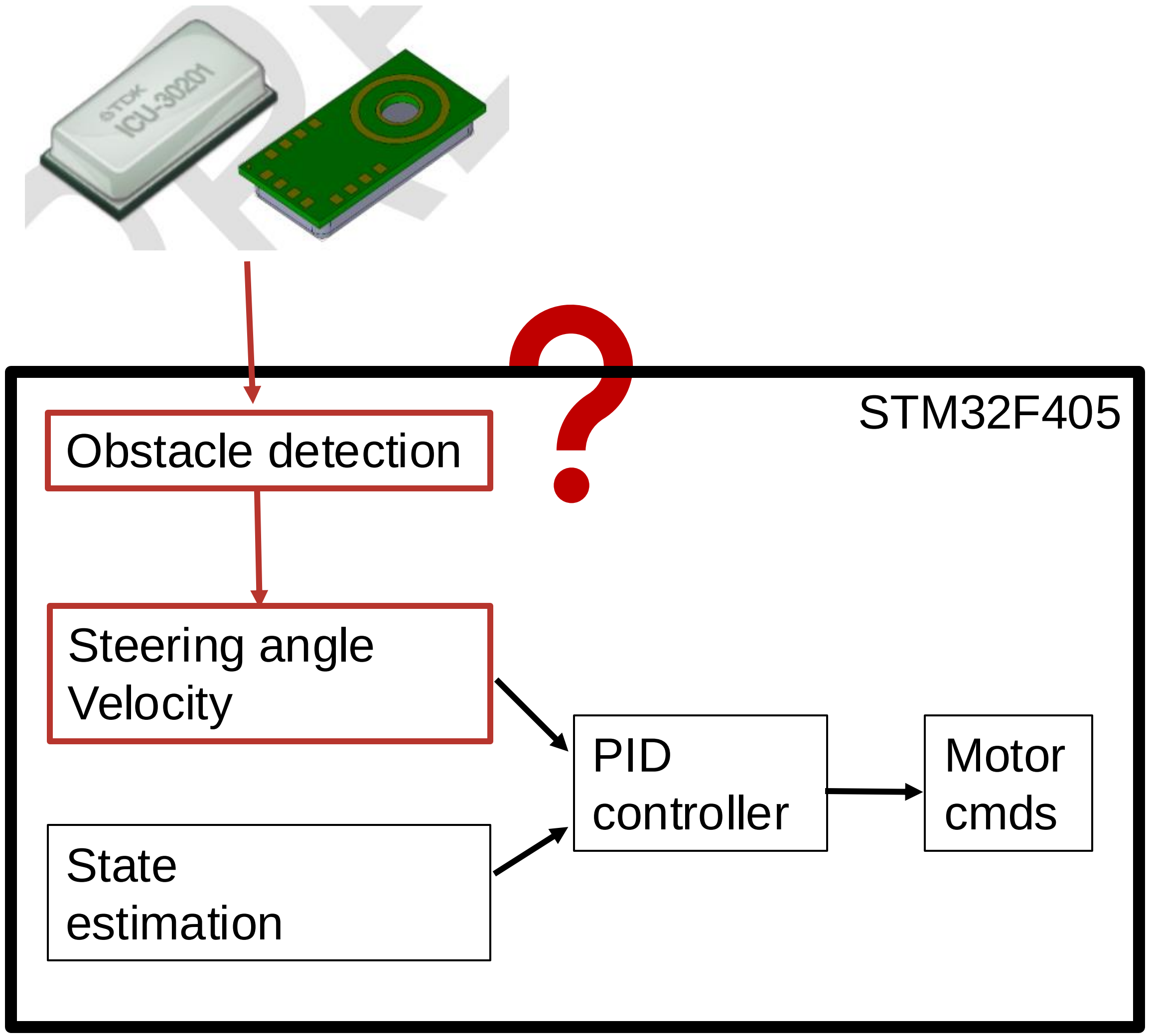
ICU-30201
- <1 mW power consumption
- 340 complex int16 samples over 4.5 m range

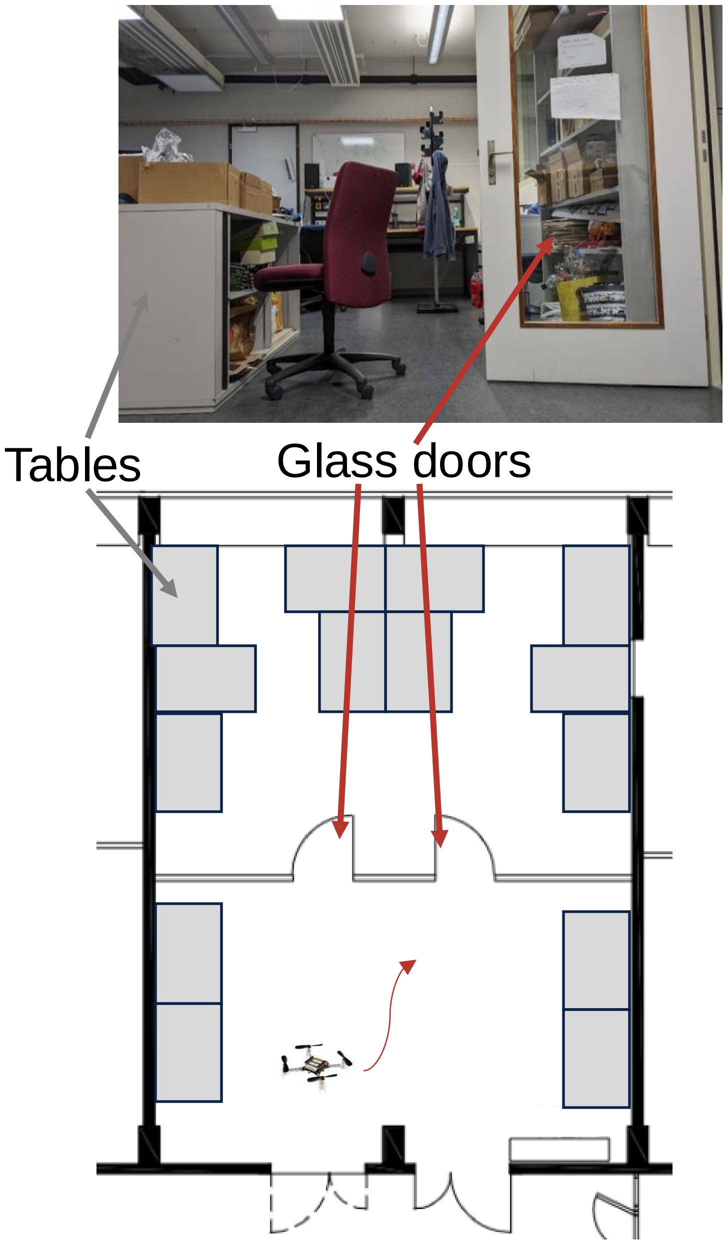


- Up to 4 ICU-x0201
- Voltage regulator
- GPIO expander for trigger/interrupt pins

Weight: 34g + 3g (BatDeck with one sensor)
Flight time: ~7'

Final Goal and Field Test Setup



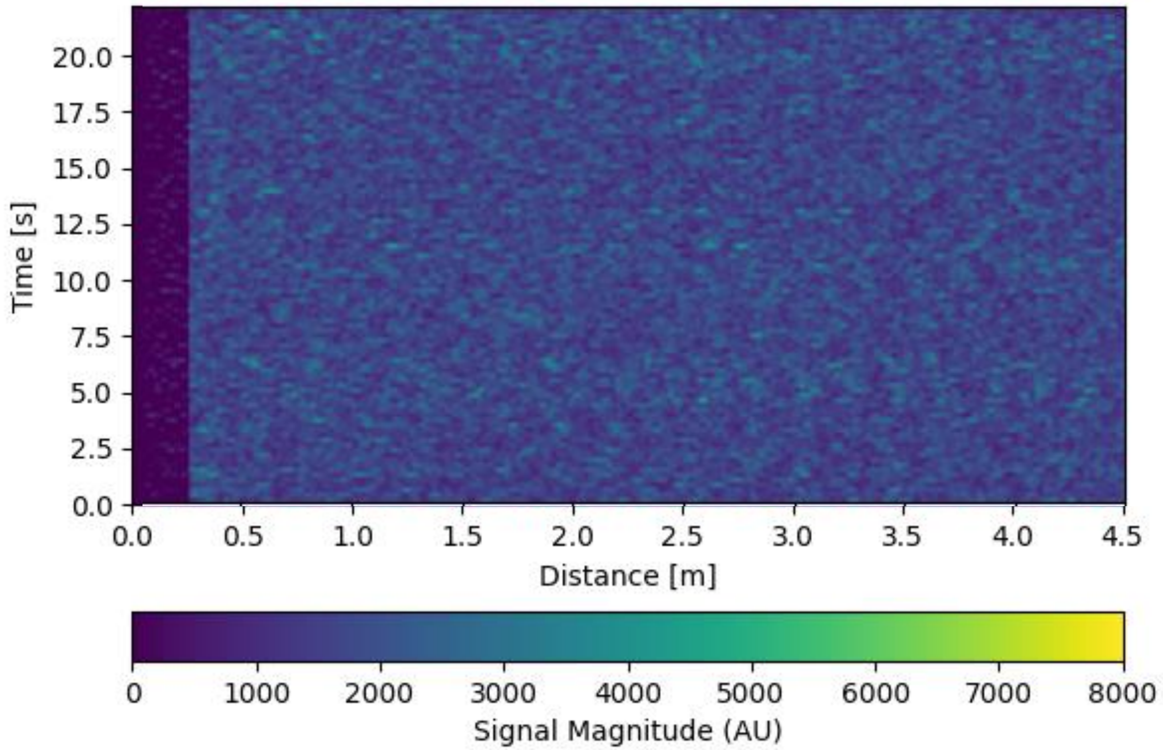


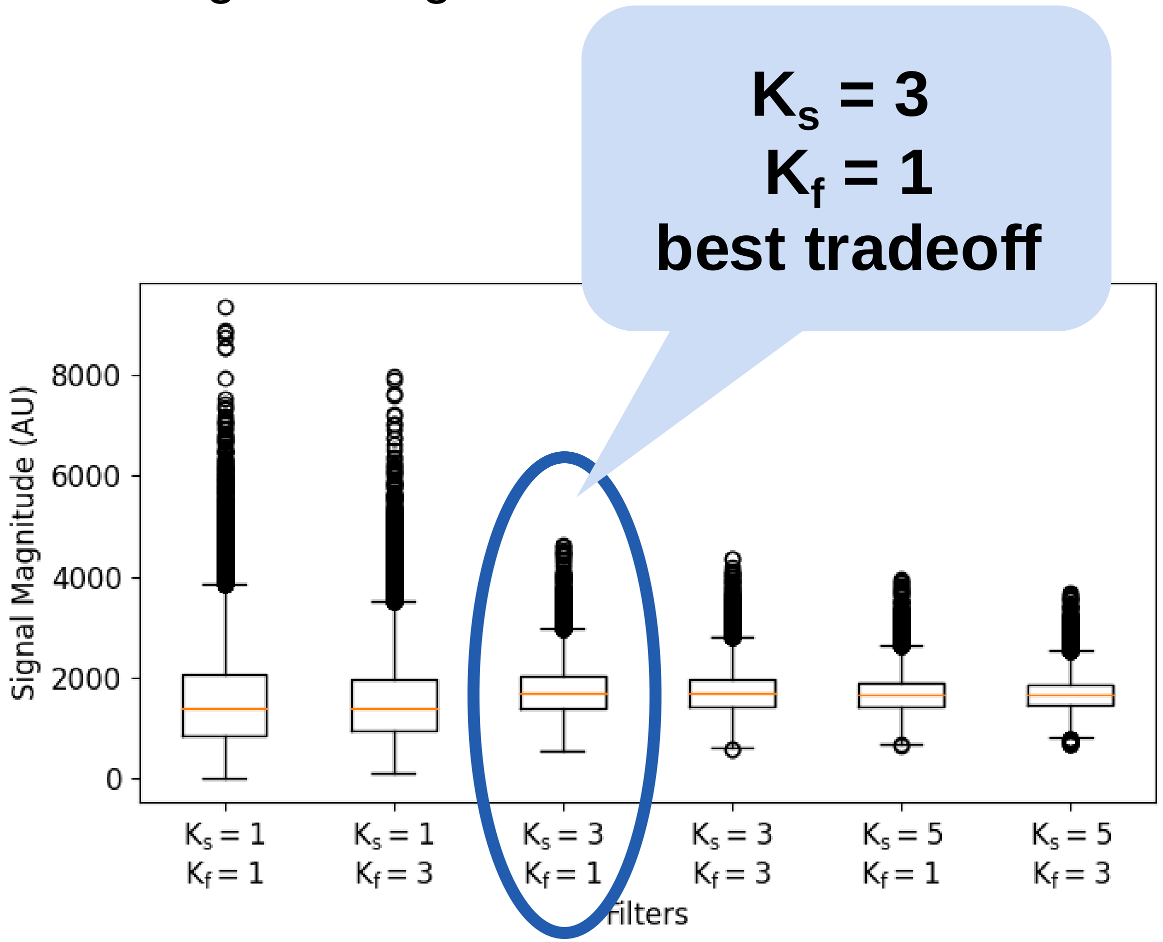
Sensor Characterization During Flight

Problem: Vibrations from motors
Solution: Filtering

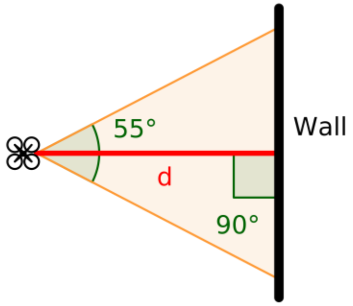
- No TX
- 33 Hz onboard acquisition/filtering
- Logged 100 (filtered) samples @4.5 Hz

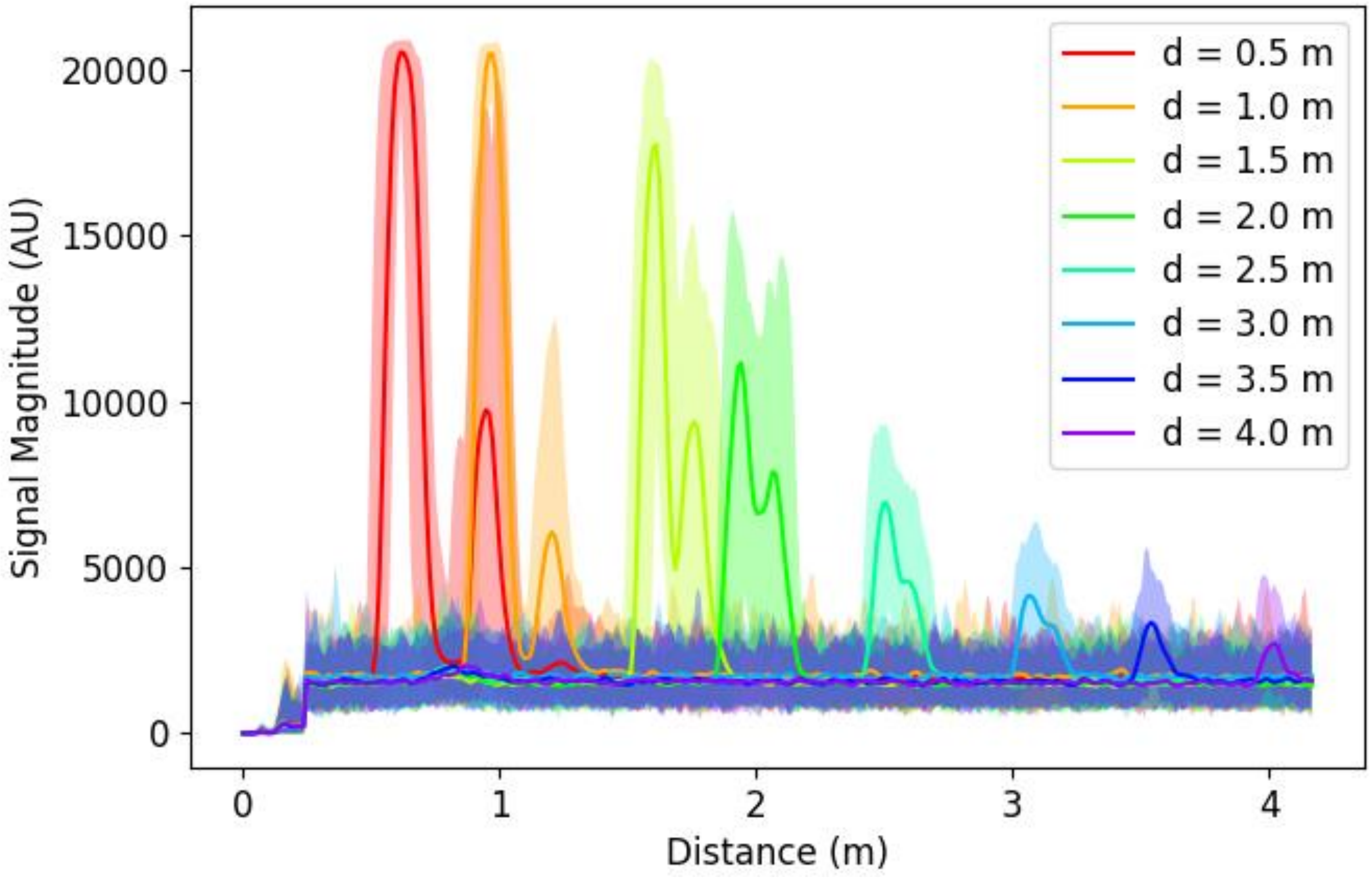
Average filtering in slow and fast time



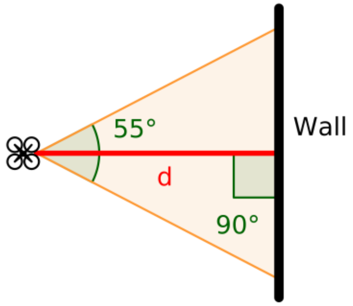


Sensor Characterization during Flight in Front of a Concrete Obstacle



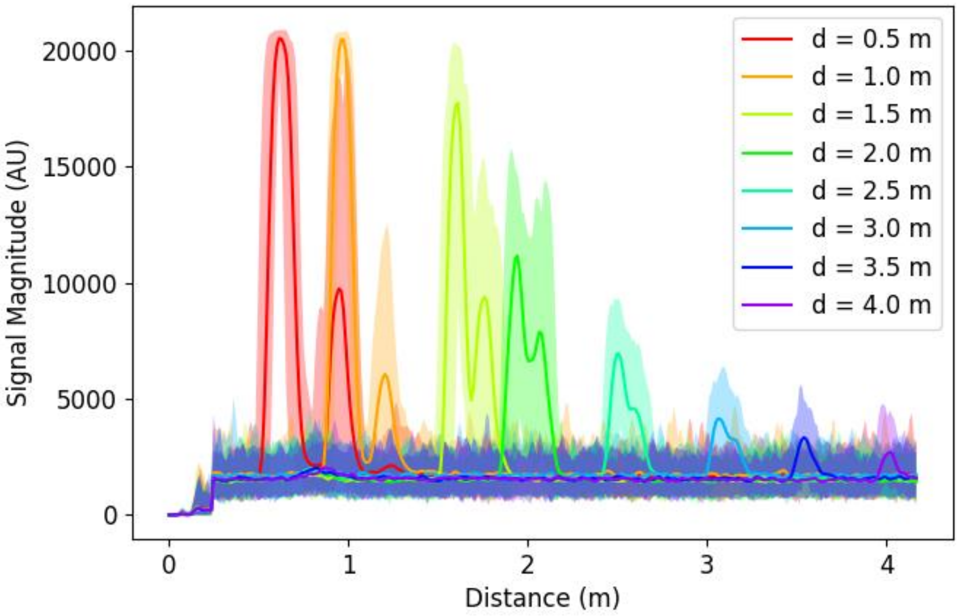


Concrete vs Glass Obstacle

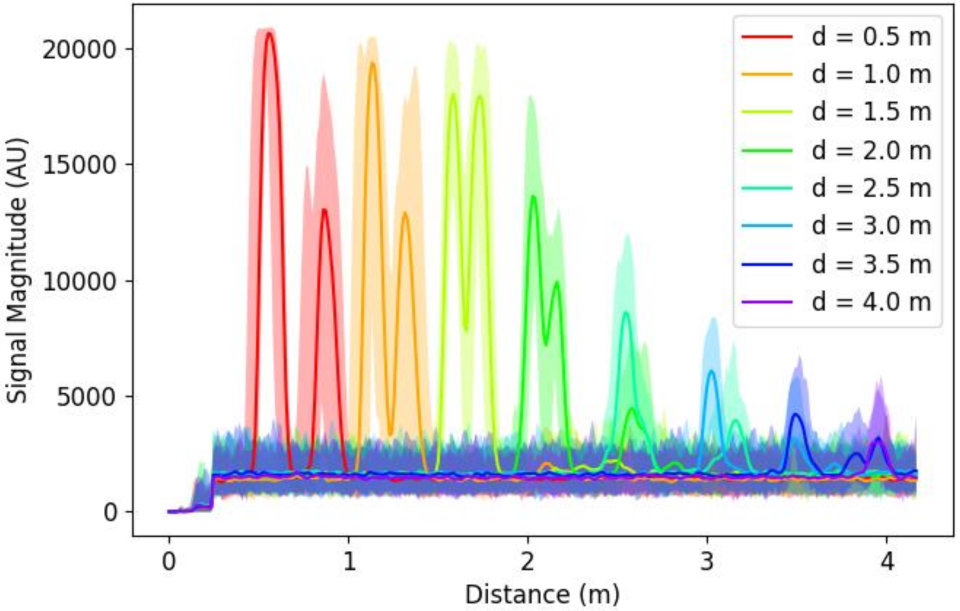


Threshold: 6000

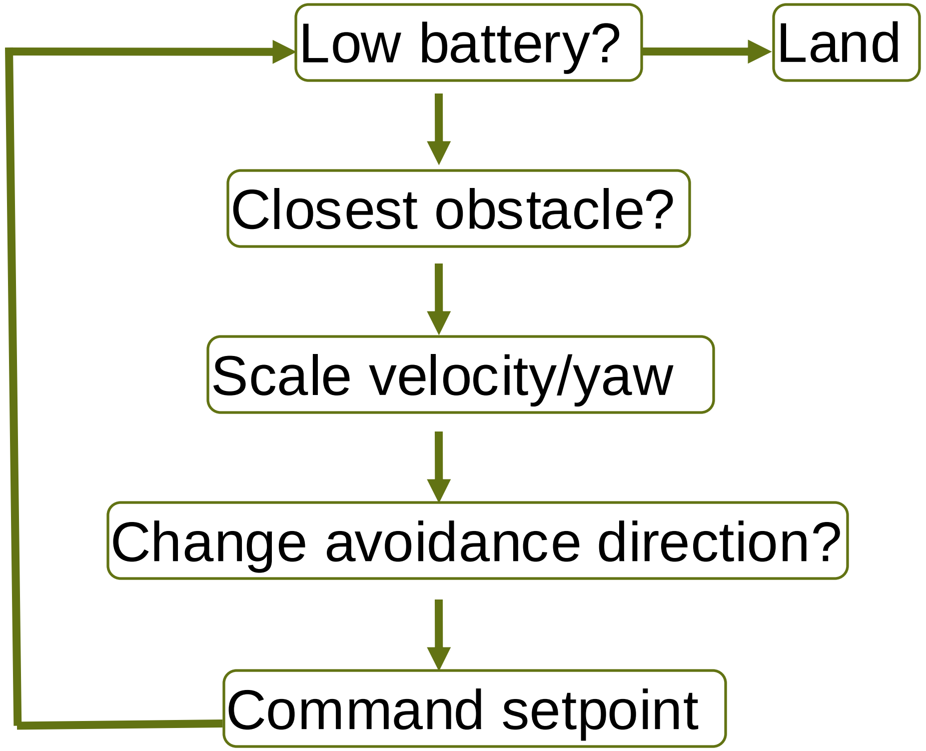
Concrete

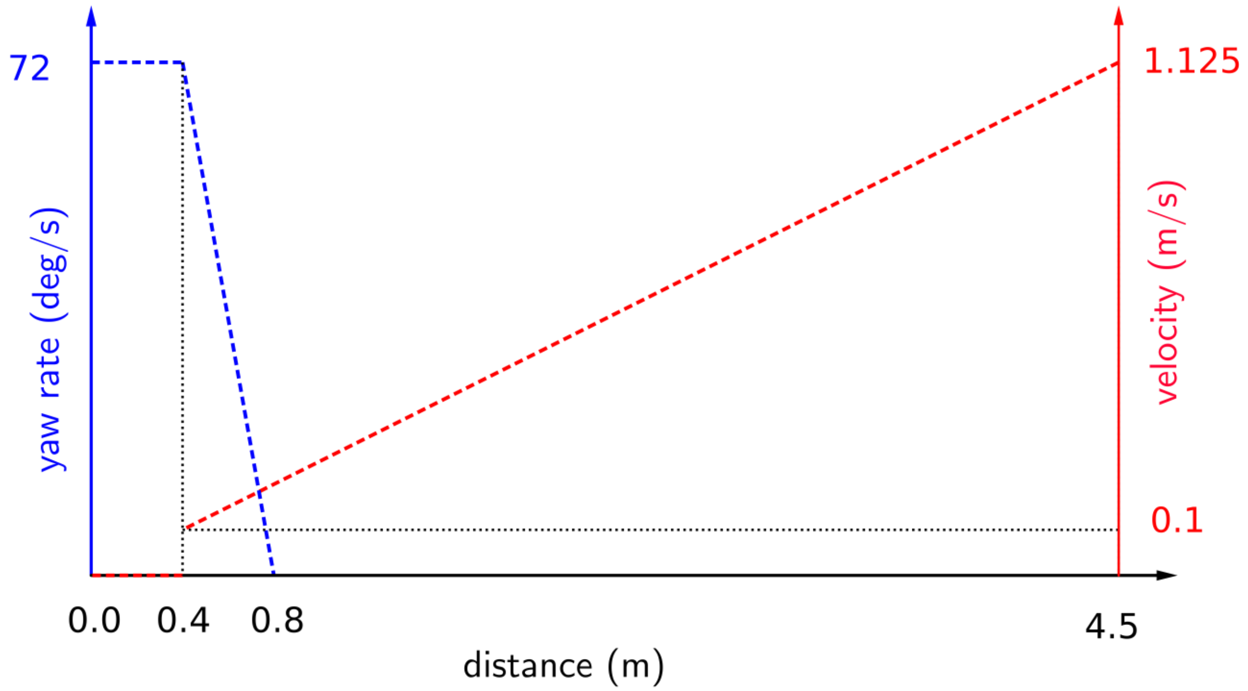


Glass

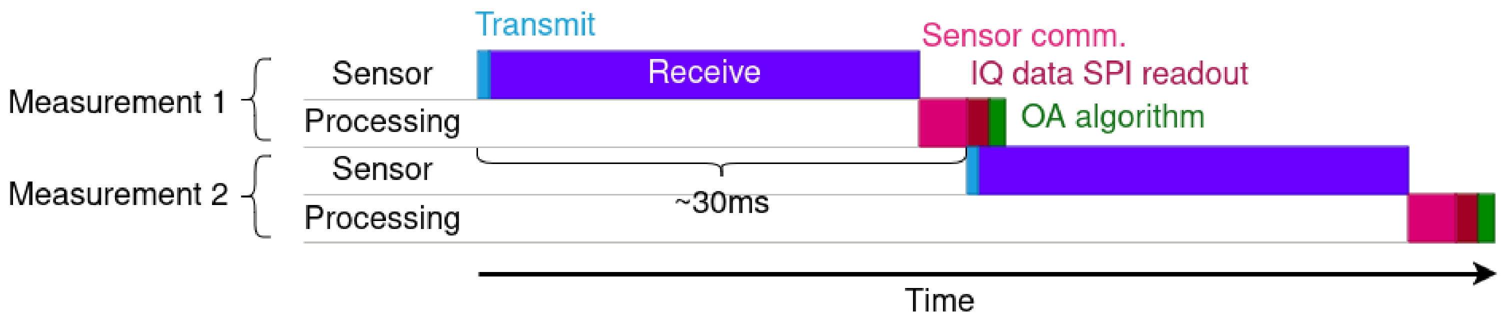


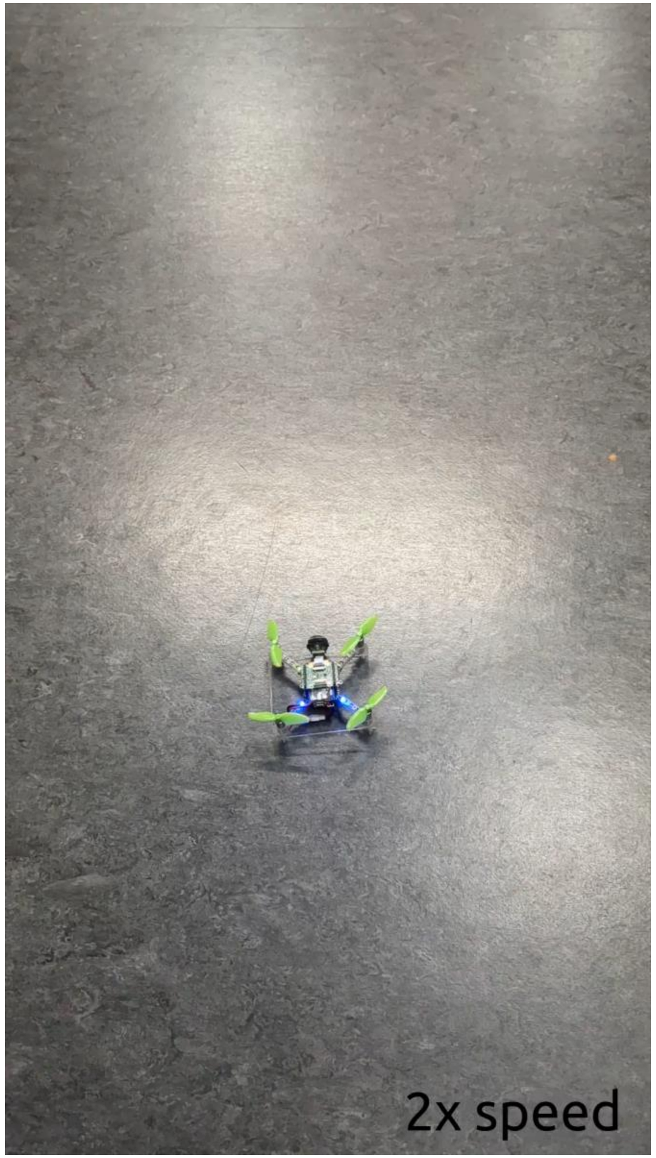
Obstacle Avoidance Algorithm





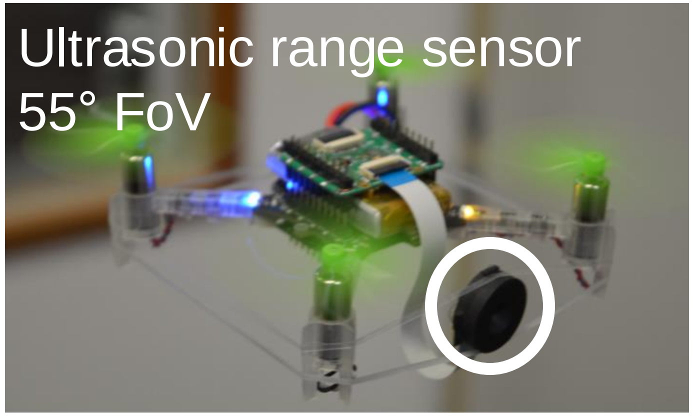
BatDeck Obstacle Avoidance Performance

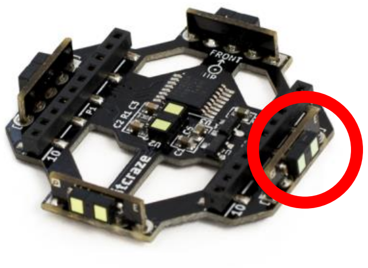




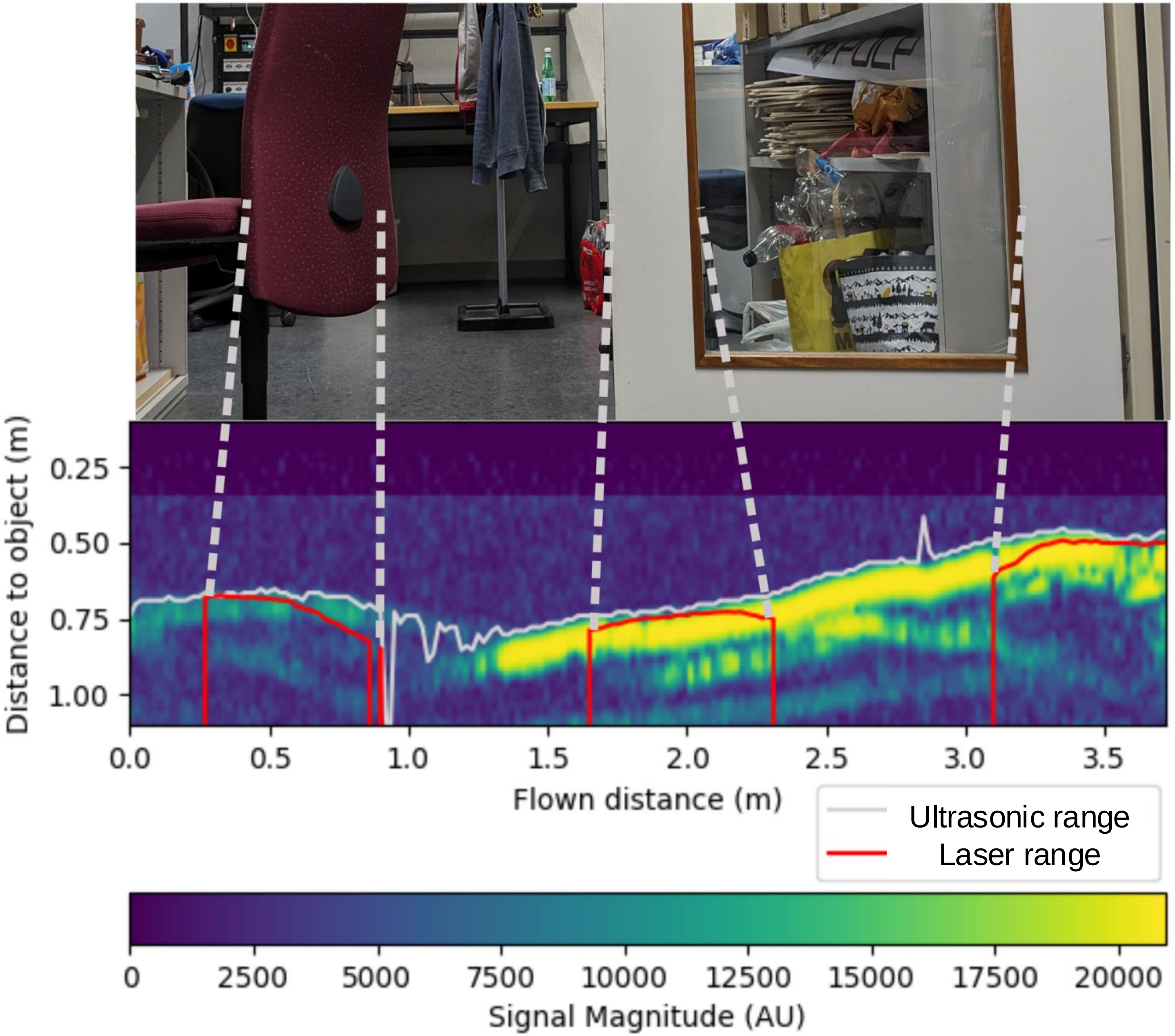
- 33 Hz sensor acquisition
- Additionally 2.5% on STM32F4
- <1mW for sensor
- 10 test flights:
  - 4'22" and 86 m on average
  - 50% without crash

Ultrasonic vs Laser-based Sensors for Obstacle Avoidance





Laser range sensor
27° FoV



BatDeck: A Robust Solution for OA

Contributions:

- Motor noise characterization
- ICU-30201 characterization
- Proof of concept obstacle avoidance
- Comparison to laser ranger

Future work:

- Extension to **multiple** sensors
- **Fusion** with e.g. laser ranger
- Extension to state estimation, mapping, obstacle recognition,...