Drone Introduction

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Presentation

BSc and MSc in Mechatronics Engineering in **Politecnico di Torino**
Master thesis in **Cal State LA**

PhD in multi-modal aerial robots with **TUM** and **Imperial College**

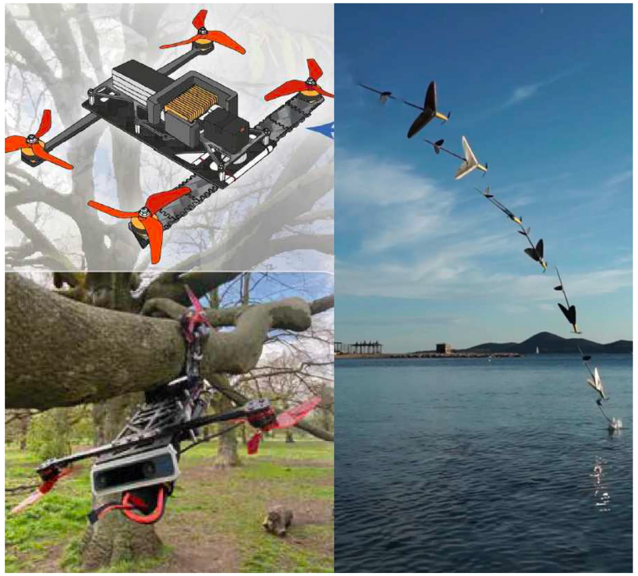
PostDoc in aerial-aquatic robots with **EPFL** and **EMPA**

Learning goals

- Define unmanned aircraft, automated system and autonomous system.
- Discuss the different types of drones.
- Describe the fixed-wings platform.

What can drones be used for?

- Why a module on UAV and MAV Technologies?
  - One of the most rapidly expanding areas of the aerospace industry
  - Of interest to government, private enterprises and research organisations
- Overview of applications: agriculture, underwater forest etc..



Zheng et al., Nature Scientific Reports, 2022
Siddall et al., Bioinspiration and Biomimetics, 2014

Definitions

Unmanned Aircraft: An Unmanned Aircraft (sometimes abbreviated to UA) is defined as an aircraft that does not carry a human operator, is operated remotely using varying levels of automated functions, is normally recoverable, and can carry a lethal or non-lethal payload.

Unmanned Aircraft System: An unmanned aircraft system is defined as a system, whose components include the unmanned aircraft and all equipment, network and personnel necessary to control the unmanned aircraft.

Definitions

There are lots of other terms for UAV, these include,

Drones, remotely piloted vehicles (RPV), Unmanned Aircraft Systems (UAS), Unihabited Combat Aerial Vehicle (UCAV), Organic Aerial Vehicle (OAV), Uninhabited Combat Aircraft Systems (UCAS), Remotely Piloted Aircraft (RPA), Remotely Piloted Helicopters (RPH), Aerial robots, Remotely Piloted Aircraft Systems (RPAS)

Generally, we will use UAV or UAS. UAS includes the system – for example, the aircraft, ground station and communication systems.

Definitions

Automated System: In the unmanned aircraft context, an automated or automatic system is one that, in response **to inputs from one or more sensors**, is programmed to logically follow a **pre-defined set of rules** to provide an outcome. Knowing the set of rules under which it is operating means that its output is predictable.

Examples include systems which undertake take-off and landing, pre-programmed route following (especially in the event of communication loss) etc. Most UAVs have some ***level of automation****. Aircraft which carry out the full mission without human intervention are automated.*

Definitions

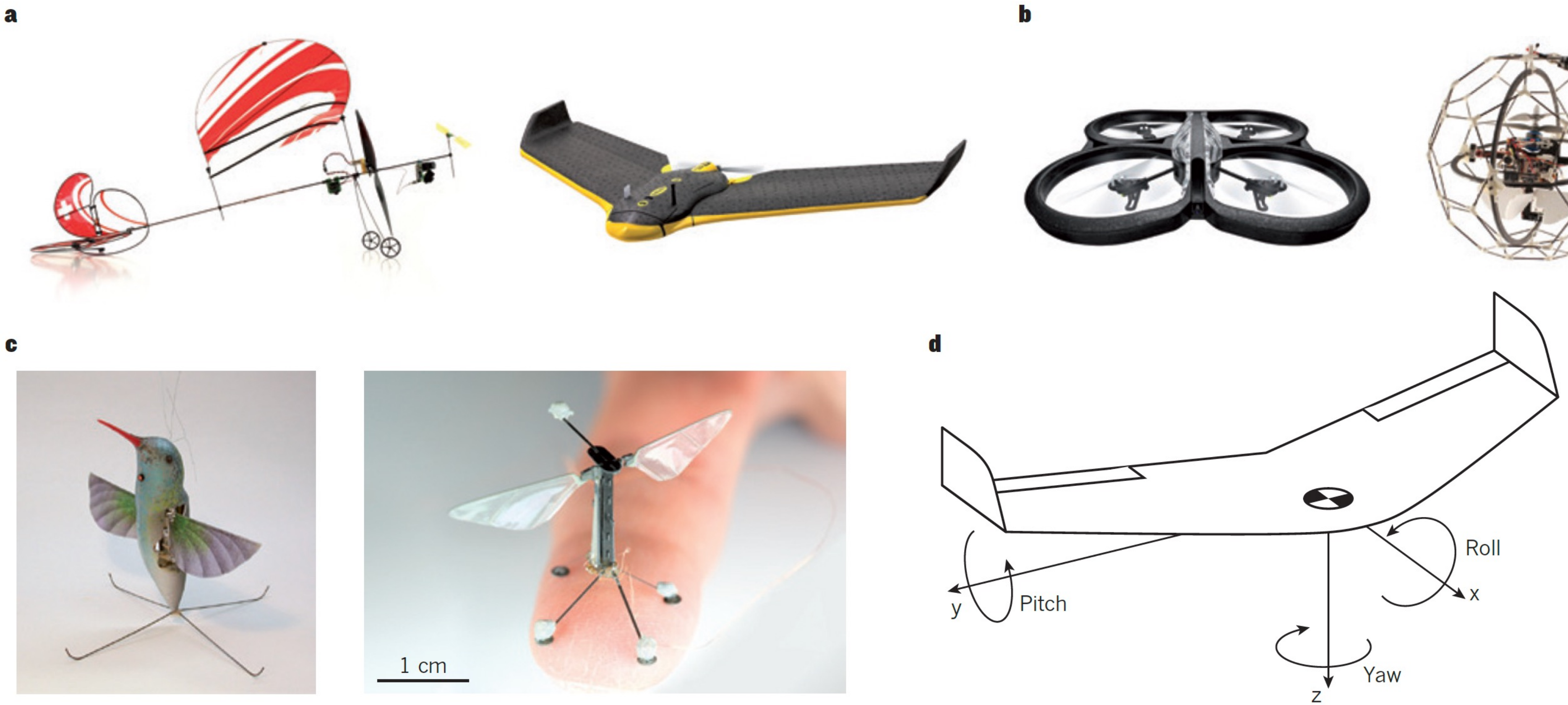
Autonomous System: A system that interprets **high-level** intent, **perceives** its environment, and **independently** selects **actions** to achieve a desired state without requiring **human** oversight, though supervision may be present. While its overall behavior is predictable, individual actions may not be.

Autonomous systems have some level of self-awareness and their inputs are indistinguishable or superior to manned aircraft. As such there are not any UA platforms that can be described as autonomous by this definition – it is this definition which has particularly serious moral implications.

Types of Drones

Fixed-wing drones

Rotorcraft



Flapping wings

Floreano et al., Nature, 2016

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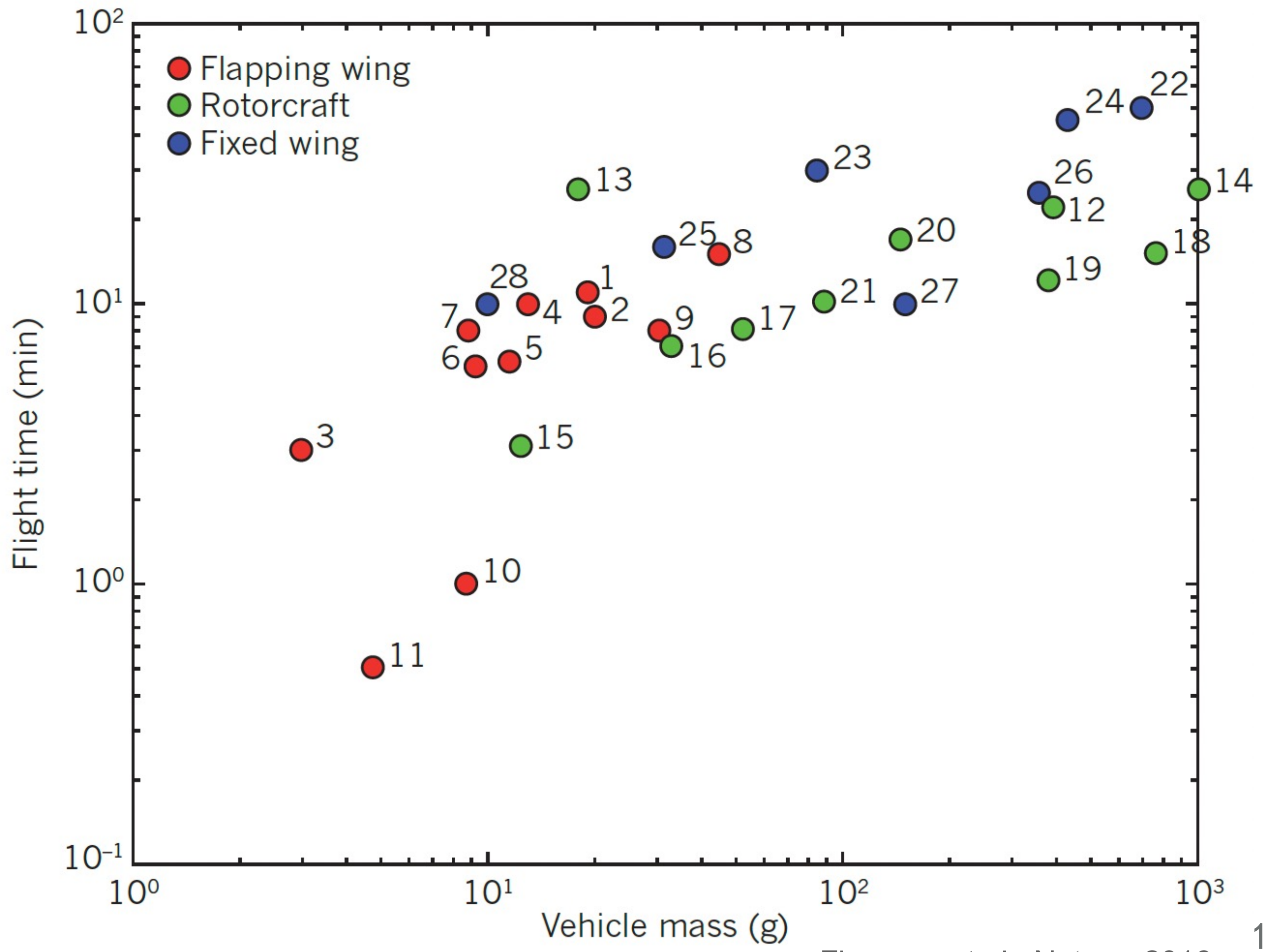
Types of Drones: Endurance

One key difference between drone types is **endurance**. Fixed-wing drones offer the highest endurance, followed by rotorcraft and then flapping-wing drones. As a result, they can carry heavier **payloads** and support longer missions.



Floreano et al., Nature, 2016

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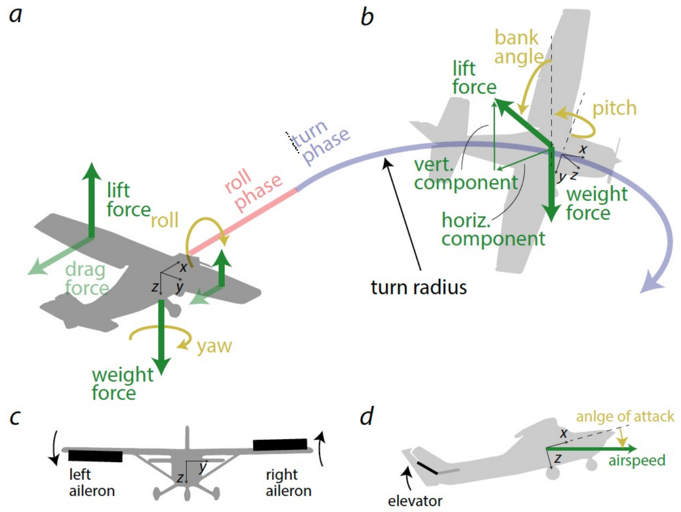
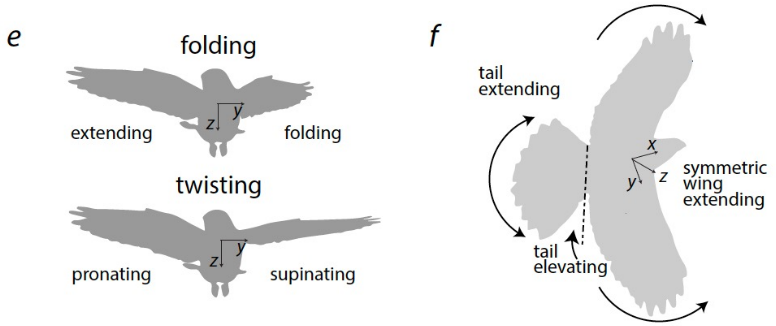
Types of Drones: Maneuverability and Stability

Higher **maneuverability** comes at the cost of **stability** and control complexity. Large aircraft are stable but hard to maneuver, while more agile systems require continuous control. **Fixed-wing** UAVs are generally more **stable** but less agile, whereas rotorcrafts and flapping-wing drones offer high **maneuverability** with lower inherent stability.

Maneuverability

Stability

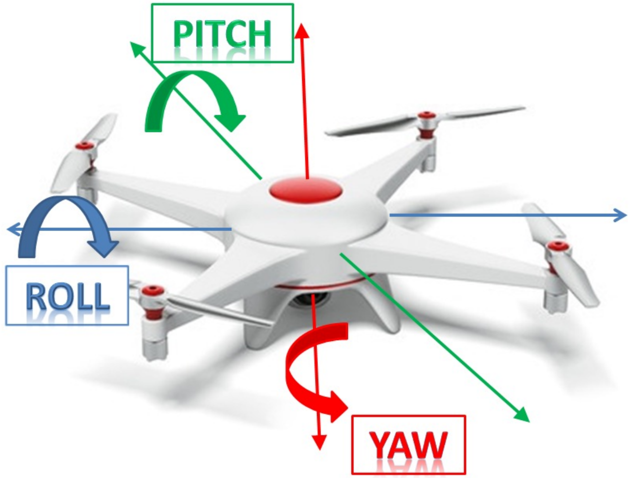


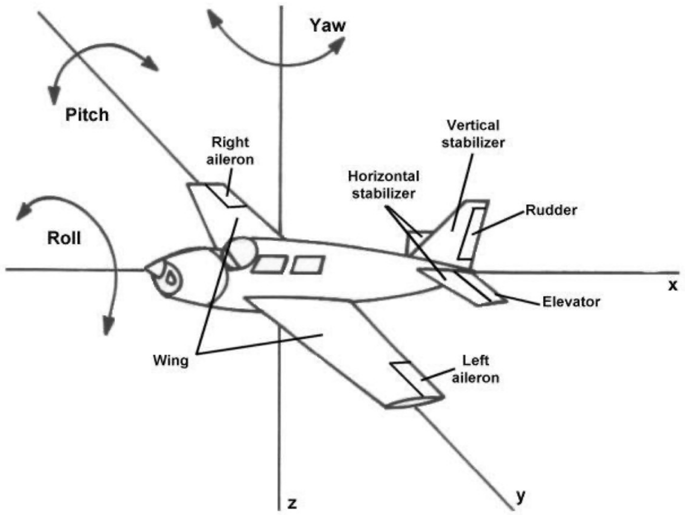


Ajanic et al., Nature Communications, 2022

Types of Drones: Manoeuvrability and Stability

- Rotocraft and flapping-wing UAVs are highly **agile**, capable of **hovering** and navigating tight spaces.
- However, they **lack natural stability** and require constant control input to stay balanced.
- Quadcopter and flapping-wing designs respond **quickly** but need continuous feedback systems.
- Their agility comes with higher **power consumption** and more complex flight dynamics than fixed-wing UAVs.

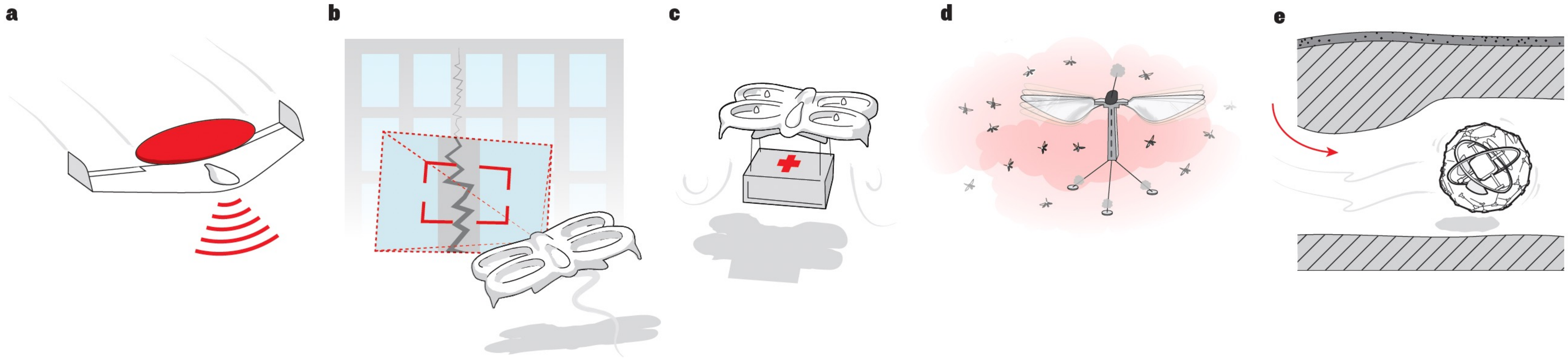




J. Yoon, "Adverse Yaw and Aircraft Turns," 2001

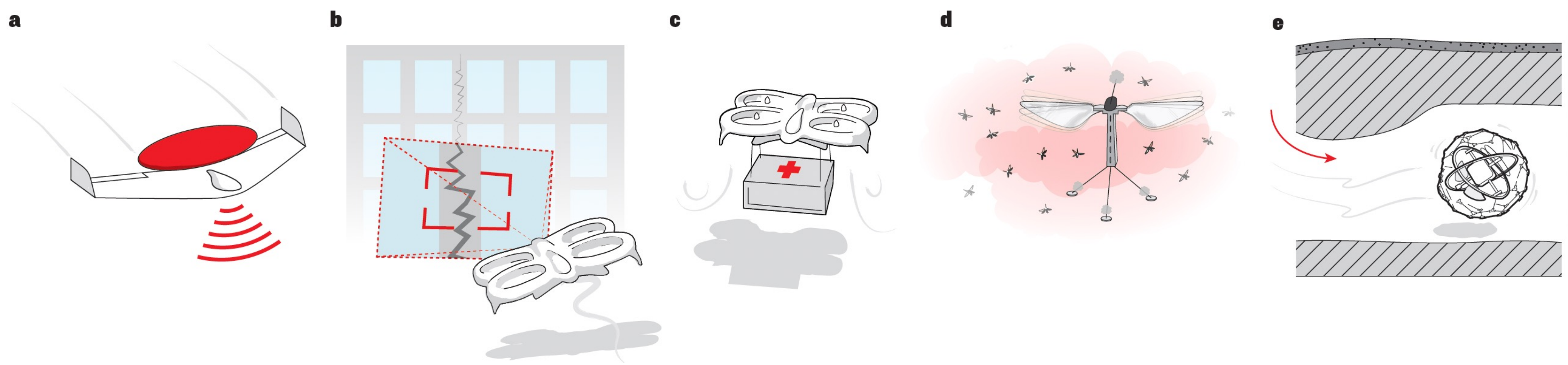
Types of Drones: Applications

Based on the differences we saw so far, which **applications** are common for fixed-wing, rotorcrafts and flapping-wings?



Floreano et al., Nature, 2016

Types of Drones: Applications



The type of UAV determines its **applications**. Fixed-wing UAVs, due to their higher endurance, are suitable for **surveillance** and search and rescue missions. Rotorcraft are ideal for **precise** tasks such as monitoring. Flapping-wing UAVs, because of their small size and low noise, are well-suited for wildlife **monitoring**.

Floreano et al., Nature, 2016

Fixed-wing UAVs: historical perspective

D_3

Dull

Dirty

Dangerous

Dull – where the mission contains a low workload, such as long duration surveillance

Dirty – The mission might be in an environment unsuitable for humans

Dangerous – missions where human life is at risk

And/or

Covert – lower detectability of UAVs, no aircrew

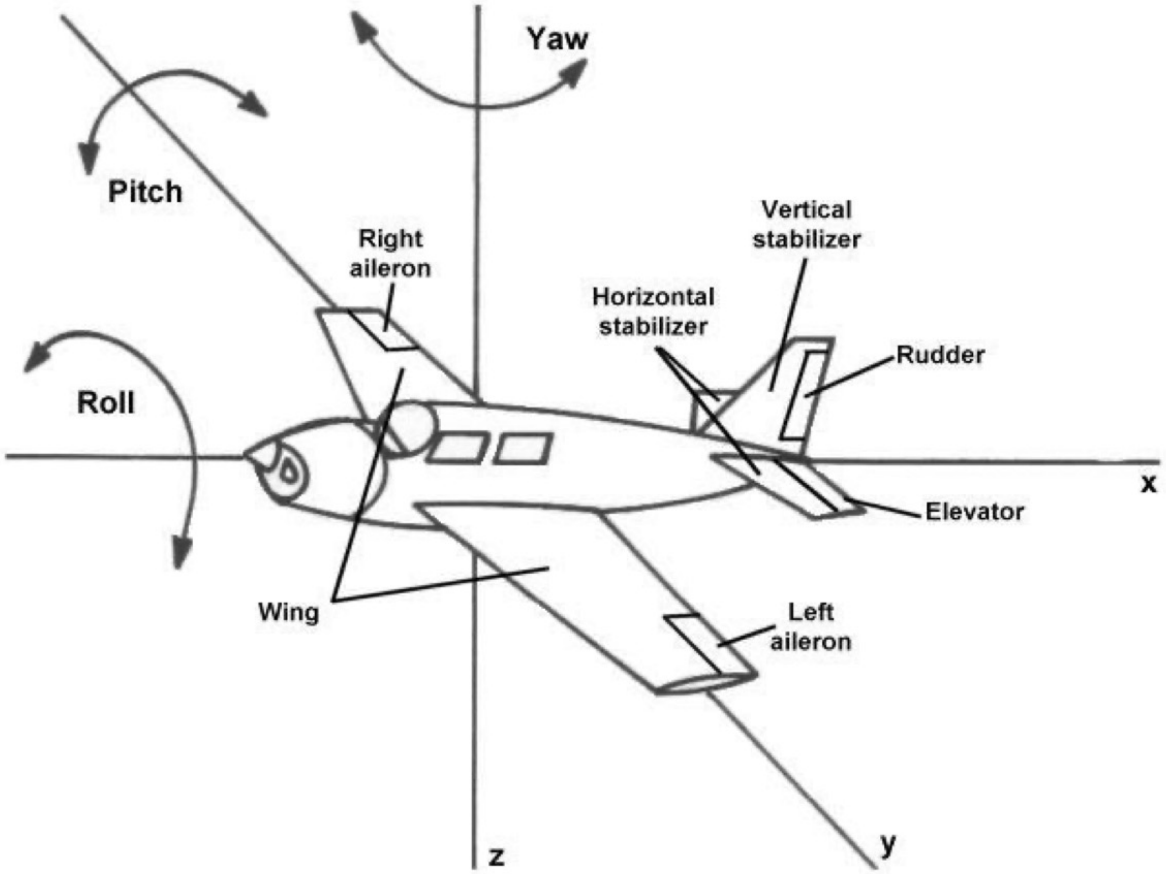
Research – lower hazard, less redundancy, faster development

Economic Reasons – Smaller, lower cost, no aircrew

Fixed-wing UAVs: Navigation

Fixed-wing drones use the same fundamental control surfaces as manned aircraft.

Control via aerodynamic surfaces:
- **ailerons** (on the outer wings) for roll
- **elevators** (on the horizontal tail) for pitch
- **rudder** (on the vertical tail) for yaw
- throttle.



Rahman et al., MATEC Web of Conferences **152**, 02023 (2018)

Manned vs Unmanned

- **Unmanned**: Not just the absence of the flight crew but
  - No windows
  - Furnishings (seat, ejector seats etc)
  - Doors
  - Instrumentation and avionics
  - Control interface
  - Cabin environmental controls and pressurisation
  - Survival kit
- This is offset by the additional weight of some additional systems, such as,
  - Autopilot and other avionics
  - Flight control actuation
  - Line-of-sight communications

Boeing 757, first generation flight deck

Lim et al., Progress in Aerospace Sciences, 2018

Manned vs Unmanned

- For a tactical UAS (such as the Cessna O2 this can save 275kg of weight (around 10% of the maximum takeoff weight!)
- For combat aircraft this could be even more of a weight saving.
- This weight saving can be used to increase capability, range etc – or result in a significantly smaller aircraft
- Remember that 10% weight reduction leads to
  - A lower lift requirement
  - Less drag
  - Less thrust
  - Less fuel
  - Less weight

British MQ-9A Reaper

https://en.wikipedia.org/wiki/Unmanned_combat_aerial_vehicle

Manned vs Unmanned

- What about the performance?
  - Putting a human in the cockpit has a number of **limitations**
    - Acceleration limits
    - Pilot workload
    - Limited sensors
  - However, a human can **reason**, and react to changing and evolving situations
- One of the major reasons for aircraft loses is pilot error
  - It is questionable whether this is reduced with unmanned aircraft – often still pilot operated.
  - Can an unmanned aircraft with automatic/autonomous systems react to **unexpected situations**?

Manned vs Unmanned

- The reduced weight (relative to a manned aircraft):
  - Smaller size – better **transportability**
  - Lower cost – also due to less stringent **design** criteria
- Simpler design and less stringent design criteria can lead to faster implementation of new designs and concepts.
- However, manned aircraft technologies still typically lead operational UAVs:
  - Typical development cycle of a manned aircraft is 10-20 years
  - Typical development cycle of an unmanned aircraft is 2-4 years

Economic Reasons

UAV purchase costs are typically lower than manned aircraft

- However, may require sophisticated flight control systems compared to a manned aircraft
- Sophisticated control station

UAV	20%-40% of manned aircraft cost
UAV control station	20%-40% of manned aircraft cost
UAV + control station	40%-80% of manned aircraft cost

https://www.uavos.com/uavos-expands-its-family-of-ground-control-stations/

Economic Reasons

Operating Costs	
Interest on capital employed	40%-80%
Depreciation	30%-60%
Hangerage	20%
Crew salaries and associated costs	50%
Fuel costs	5%
Maintenance	20%
Insurance	30%

Highly dependent on application

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Drone ethical concerns

Drone ethical concerns

- Considering UAVs which are not fully autonomous (in a sense that they can make decisions) there is an argument that

"the moral, ethical and legal issues associated with the operation and use of weapons from UAVs are the same as those for manned aircraft."

UK Defence Minister Philip Dunne (2012)

- Others argue that

"The biggest ethical problem with drones is that it makes killing too easy"

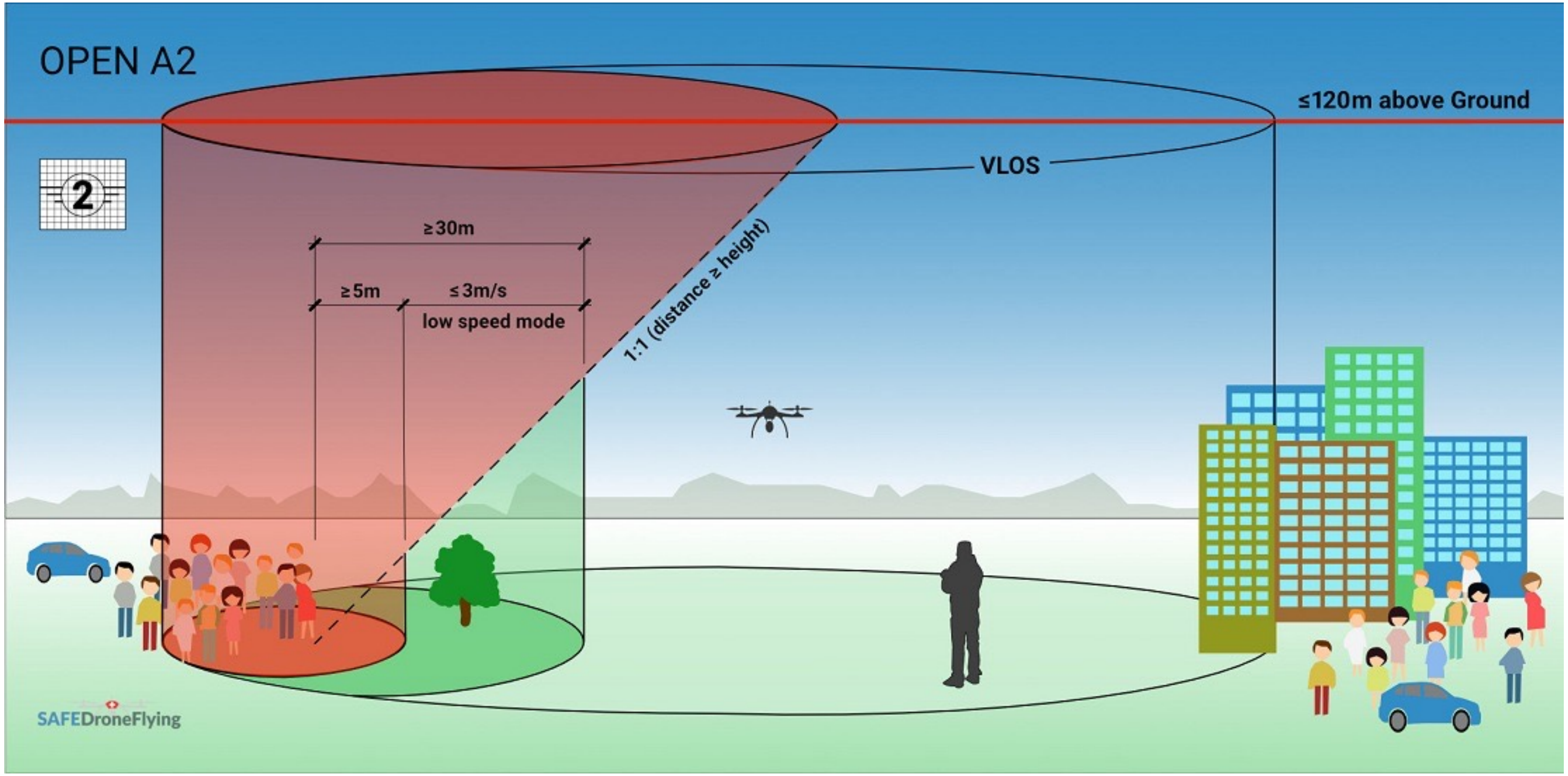
Medea Benjamin (2012):author of Drone Warfare: killing by remote control

Drone privacy concerns

420k visits in 1 month

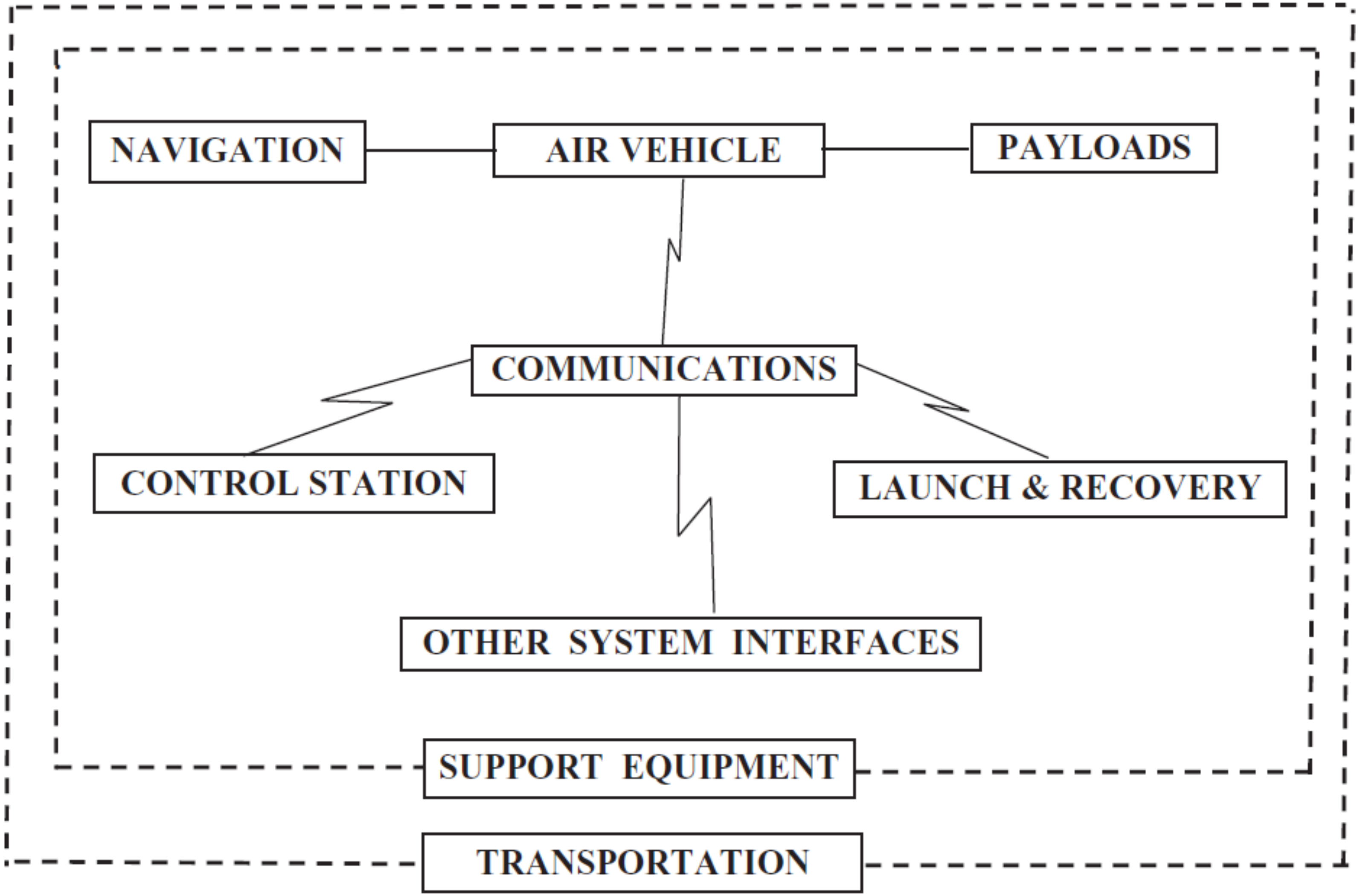
"Streisand effect"

Regulation



https://www.ch.ch/en/safety-and-justice/drones

UAV System Composition



UAV System Composition

The payload

Range from simple un-stabilized video and a fixed lens (200g)

Video system with gyro-stabilization, pan and tilt, zoom (4-5kg)

High power radar (up to 1000kg)

Potentially augmented sensors (IR/visual etc)

Stores and passive payload

Based on the mission requirements

Control Station lies at the center of the system

Communication up- and down- links used to communicate with the UAV

Communicated with other systems – weather, launch etc.

https://www.unmannedsystemstechnology.com/

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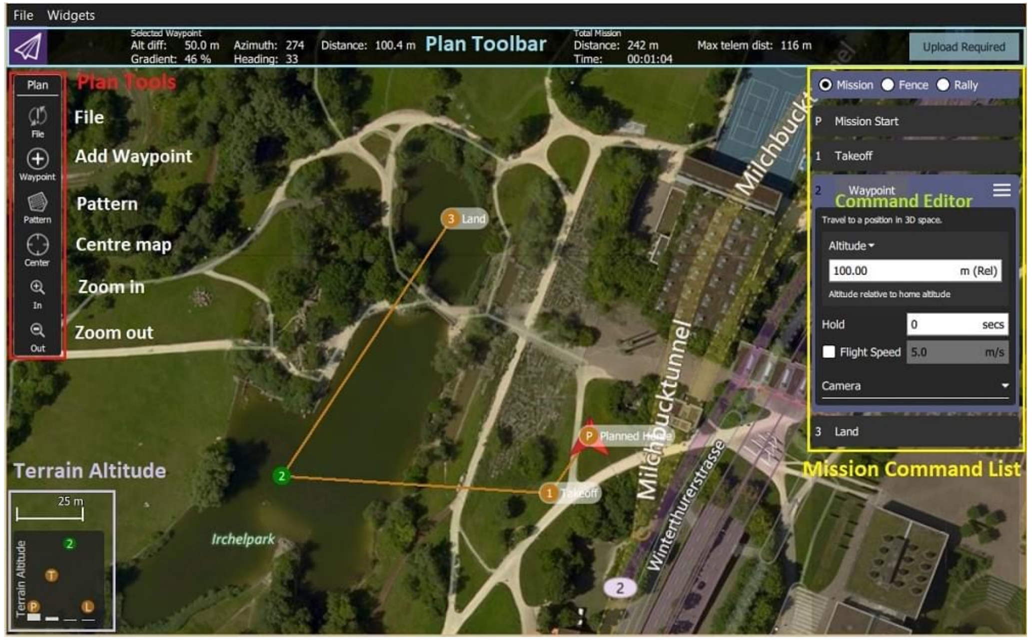
Communication

Uplink

- Transmitting flight path data to UAV
- Transmitting real time flight control to the UAV when a pilot-in-the-loop is required
- Transmit updated location data to update inertial sensors

Downlink

- Transmitting aircraft positional data
- Transmit payload imagery data
- Transmitting housekeeping data (fuel/engine state etc)



https://docs.qgroundcontrol.com/Stable_V4.3/en/qgc-user-guide/plan_view/plan_view.html

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Navigation

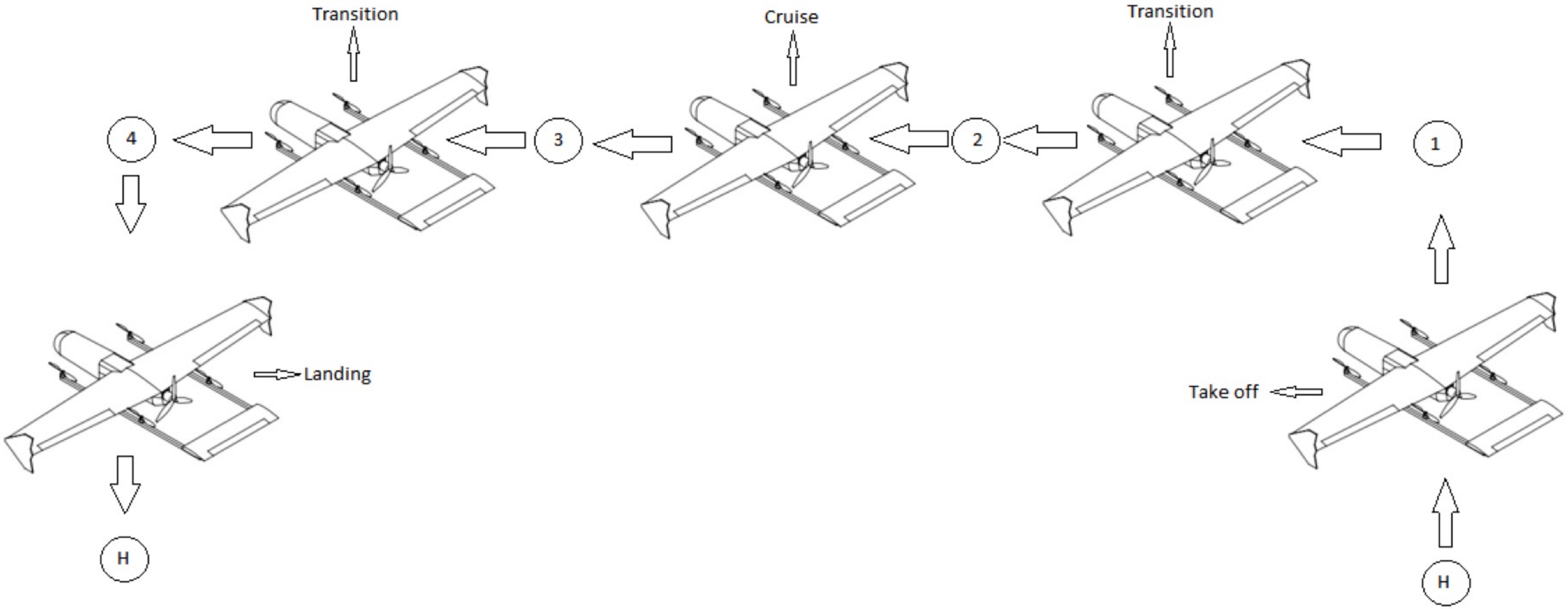
- **Basic Navigation**
  - Line of sight with the controller
- **Autonomous Flight Requirements**
  - The aircraft must determine its position
- **Navigation Methods:**
  - **Inertial Navigation Systems (INS)**
  - **GPS** (can be enhanced with Differential GPS)
  - **Augmented Navigation** (integration with other sensors like visual cues)
  - **Alternative Systems:**
    - **Radar Tracking** (ground station-based)
    - **Radio Tracking**
    - **Dead Reckoning** (using ground features for speed and position estimation)

Launch, Recovery and Retrieval

- Required for aircraft which do not have VTOL capability
- **Launch**
  - Conventional
  - Compressed air
  - Bungee
  - Rocket
  - Catapult
  - ….
- **Recovery**
  - Conventional
  - Parachute
  - Net
- Retrieval
  - Means of transporting the aircraft to the launch site

https://www.flyr-uas.com/en/launcherrecovery

Fixed-wing UAVs: VTOL



Some UAVs combine fixed-wing and rotor features (e.g. tilt-rotors) to get the best of each.

The downside of hovering is **high energy consumption**. Generating lift by pure thrust is power-intensive compared to using wings in forward flight

Rahman et al., MATEC Web of Conferences **152**, 02023 (2018)

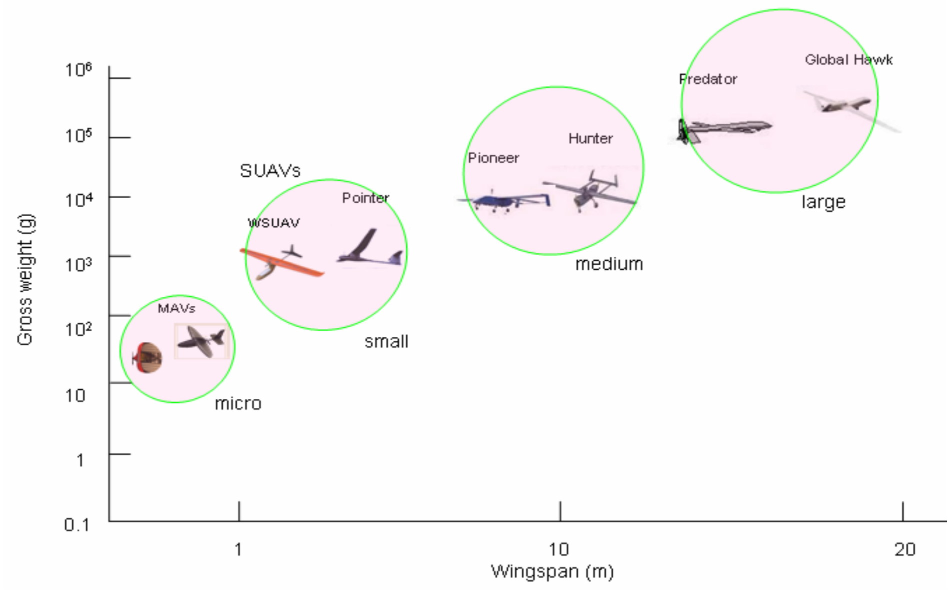
Initial Sizing

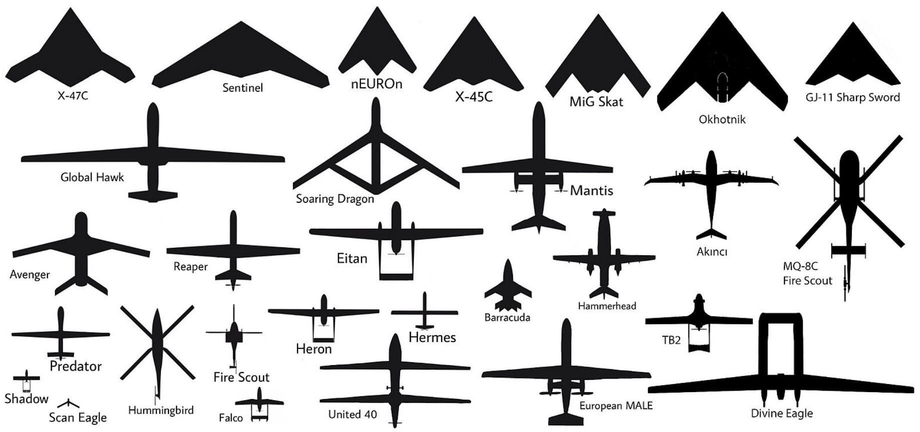
- **What is UAV Sizing?**
    - The process of determining the optimal dimensions, weight, and power requirements of an unmanned aerial vehicle (UAV) based on its intended mission.

- **Why is it Important?**
    - Ensures **efficiency** in flight performance, endurance, and payload capacity.
    - Balances **trade-offs** between weight, aerodynamics, and power consumption.

UAV Sizing Process

1. **Define Mission Parameters** (Payload, range, endurance, altitude, environment).
2. **Determine Airframe Design** (Fixed-wing, rotary, hybrid, materials).
3. **Weight Estimation & Optimization** (Structural, payload, and battery weight).
4. **Performance Analysis** (Lift, drag, thrust-to-weight ratio, stability).
5. **Iteration & Refinement** (Optimization for efficiency, control and performance).





https://it.m.wikipedia.org/wiki/UAV_Comparison.jpg

Zakaria, M. Y., & Abdallah, M. (2012). *Design and Production of Small Tailless Unmanned Aerial Vehicle (SAKR 2).*

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UAV Sizing Process

Objective: Design a UAV for environmental monitoring, determine its wing size.

Requirements: 2 kg payload, 1-hour flight time, 5 km range.

Design Choices:

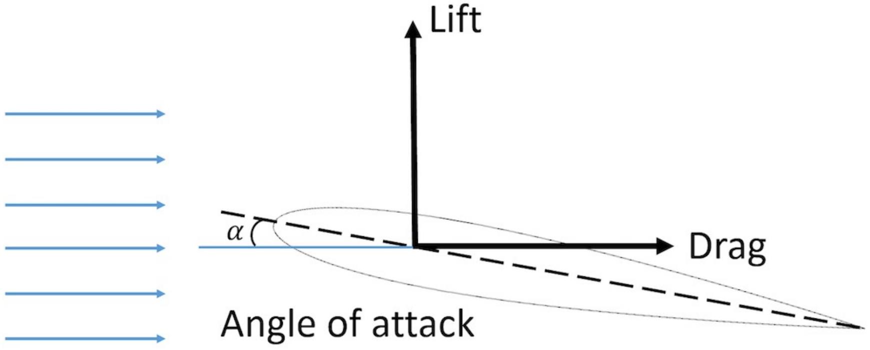
- Fixed-wing for efficiency
- Lightweight composite structure
- Li-ion battery for long endurance
- Efficient brushless motor and propeller selection

Results: Optimized UAV meeting endurance and payload needs with an aerodynamic airframe and efficient power system.

UAV Wing Design & Lift Calculation

Lift equation:

$$L = \frac{1}{2}\rho V^2 S C_L$$



Given:

Cruise speed **V**: 15 m/s

Air density ρ: 1.225 kg/m³, mass **m**: 5 Kg (2 Kg payload + 3 Kg drone)

Airfoil: **NACA 4412** Moderate camber, good lift-to-drag ratio.

Coefficient of Lift C_L: 1.2

Required Lift for Level Flight:

$$L = W = mg = 5 \times 9.81 = 49.05 \text{ N}$$

We will see more in deep aerodynamics parameters in the next lecture!

UAV Wing Design & Lift Calculation

Wing area calculation:

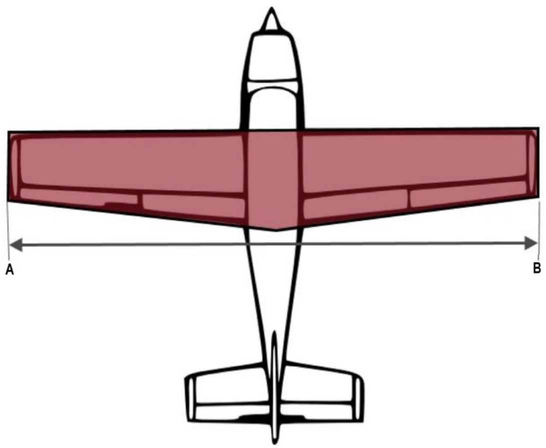
$$S = \frac{2L}{\rho V^2 C_L} = \frac{2 \times 49.05}{1.225 \times 15^2 \times 1.2} \approx 0.45 \text{ m}^2$$

Wingspan Calculation (Aspect Ratio **AR**, wingspan **b** and Surface **S**):

$$AR = \frac{b^2}{S}$$

Using typical values of AR = 8:

$$b = \sqrt{AR \times S} = \sqrt{8 \times 0.45} \approx 1.9 \text{ m}$$



Elijah et al., International Journal of Dynamics and Control, 2021

UAV Design: Scale Effects

The weight of UAVs lies in a range 2 orders of magnitude lower than manned aircraft

- Manned: 340kg (Titan Tornado) to 590,000kg (A380) or 640,000 kg (An225)
- UAV: 1kg to 12,000 kg (Global Hawk)

Leads to different designs – as scaling of length, area, volume, mass, velocity, angular inertia and frequency do not scale together

If a length scales linearly (L)

Area	L^2
Volume	L^3
Mass	ρL^3
Acceleration	Lt^{-2}
For a constant g (gravitational acceleration), t scales with $L^{1/2}$	
Velocity	$L^{1/2}$

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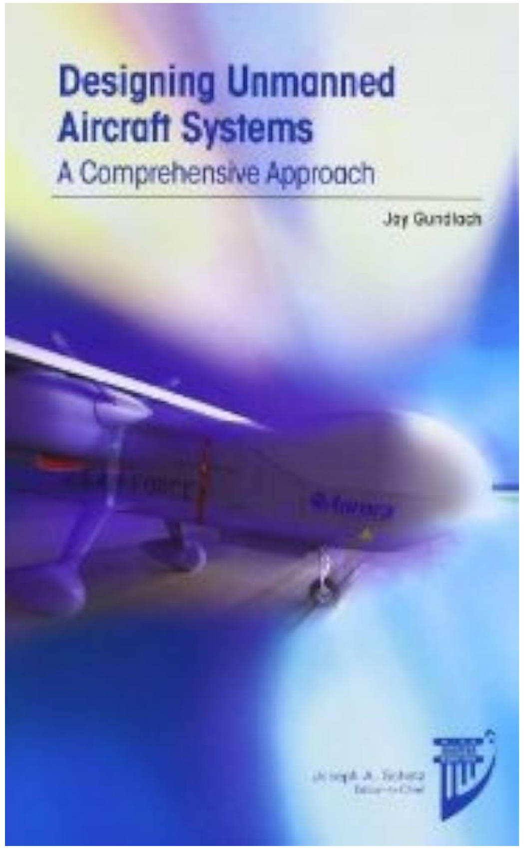
Learning goals

- Define unmanned aircraft, automated system and autonomous system.
- Discuss the different types of drones:
  - *Difference and applications*
- Describe the fixed-wings platform:
  - *Navigation, Unmanned vs Manned, Composition, Regulations and Sizing*

Source material

This lecture is based on and expanded upon in the book:
Designing Unmanned Aircraft Systems (chapter 3)



The Multi-rotor platform

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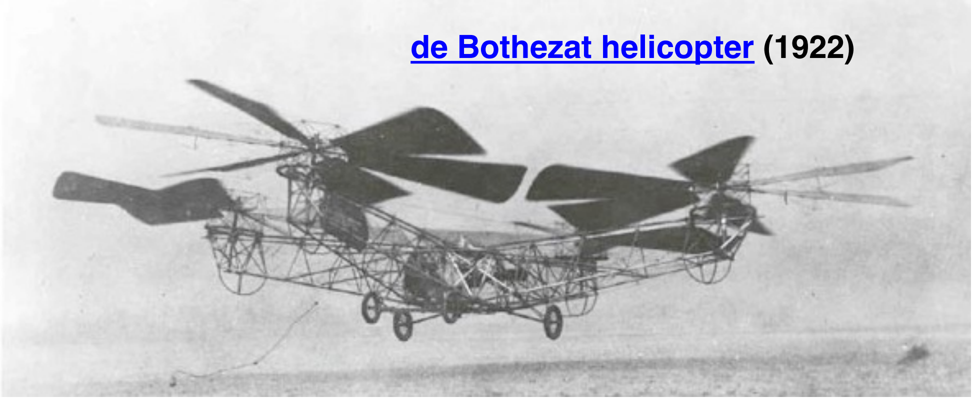
Learning goals

- Outline the rotorcraft platform's features.
- Understand common sensors employed in drones.
- Discuss a few applications of drones, including two use case scenarios.

Types of Multi-rotors

- Quadcopter, aka quadrotor helicopter
- - Helicopter is derived from Greek helix (ἕλιξ) "helix, spiral, whirl" and pteron (πτερόν) "wing"
- - (prefix quad is Latin) thus "quadrotor" is more correct than "quadcopter"


de Bothezat helicopter (1922)

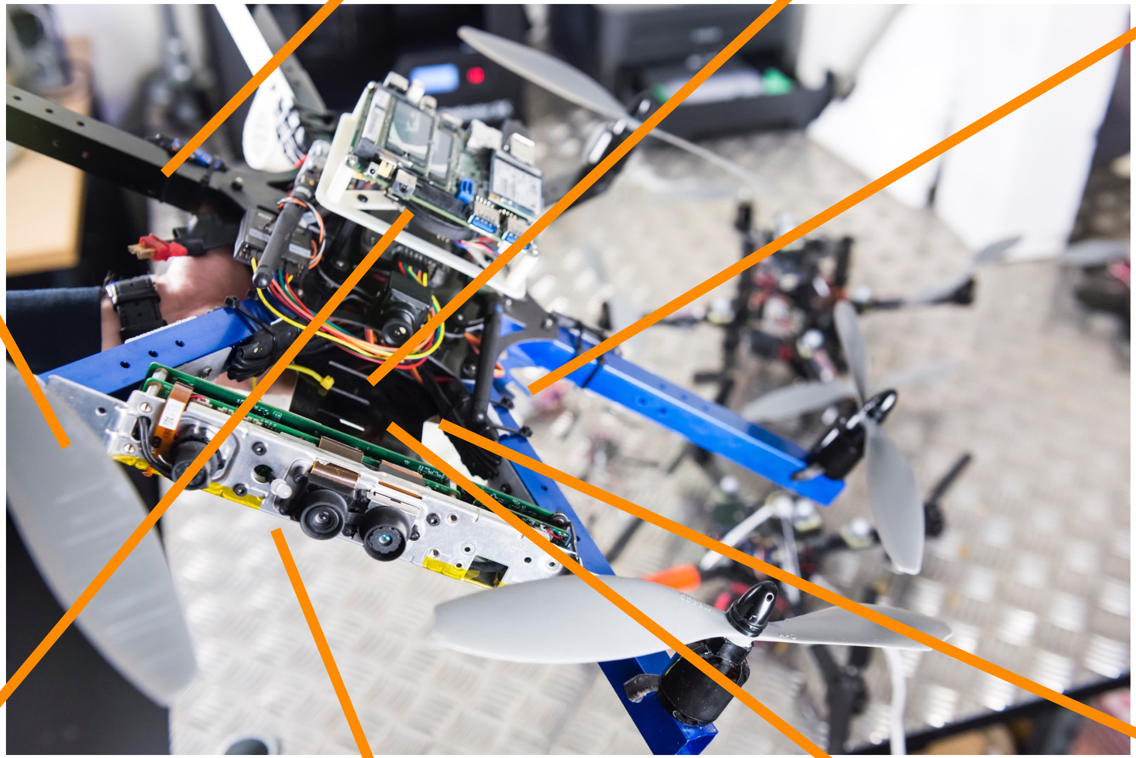
Tiny Elf TP25 Drone

Crazyflie


kmel robotics


DJI S1000+

Component overview



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Propellers

Carbon fiber propellers compared to plastic propellers

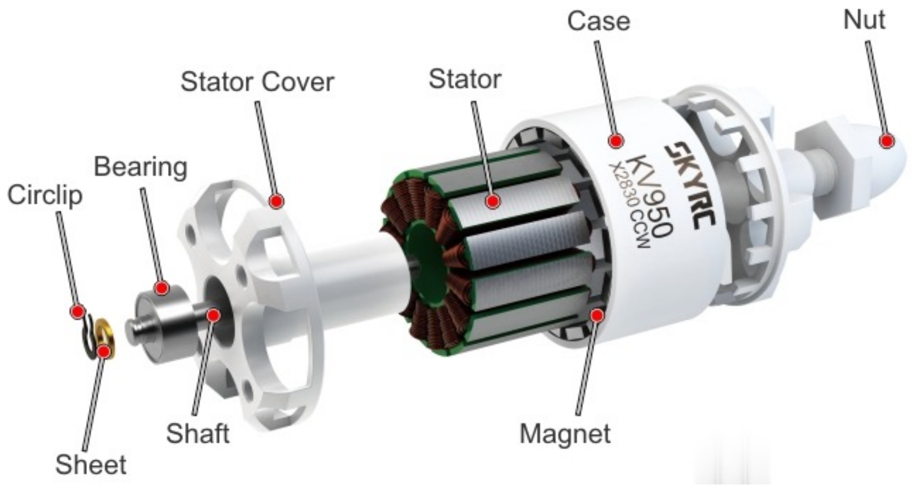
+ less vibration and flapping
+ quiet
+ more robust, and can be lighter
+ less inertia thus more responsive
+ less deformation thus more lift

- expensive
- load on motor on crash
- possibly splitter on crash

Consider shape/size in combination with motor and platform weight. Calculator tool: http://www.ecalc.ch/xcoptercalc.php?ecalc&lang=en

Motor

Typically, brushless motors and electronic speed controllers (ESC) are used due to high performance and controllability



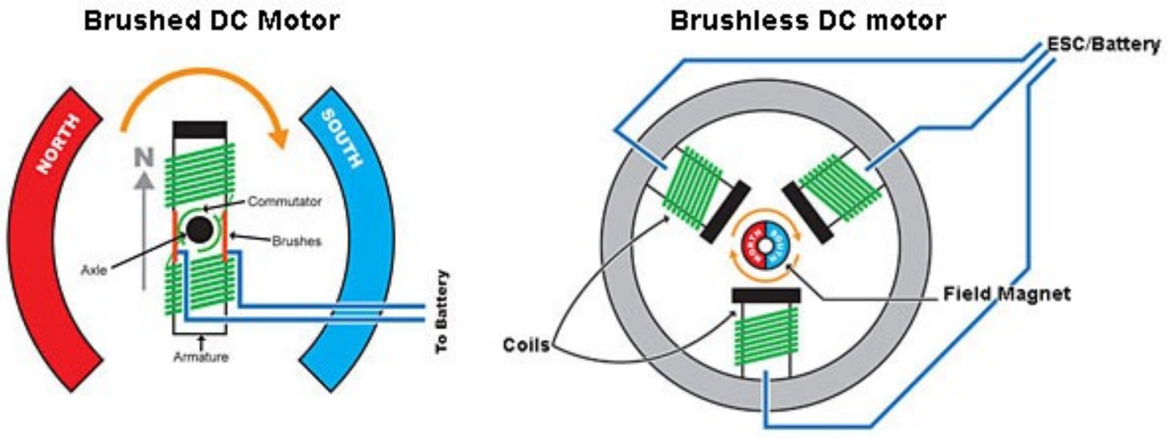
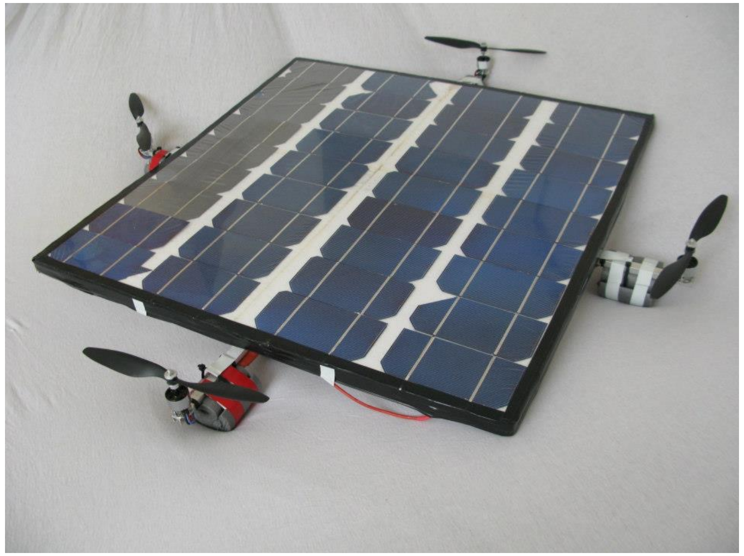


image credit: http://www.thinkrc.com/faq/brushless-motors.php

Batteries

- Most often Lithium Polymer or Lithium Ion batteries
- Typical flight times are 10-30min, depending on payload
- Emerging: Fuel-cells, Metal-air batteries, combustion engines
- Energy harvesting: Solar cells, soaring flight, induction charging



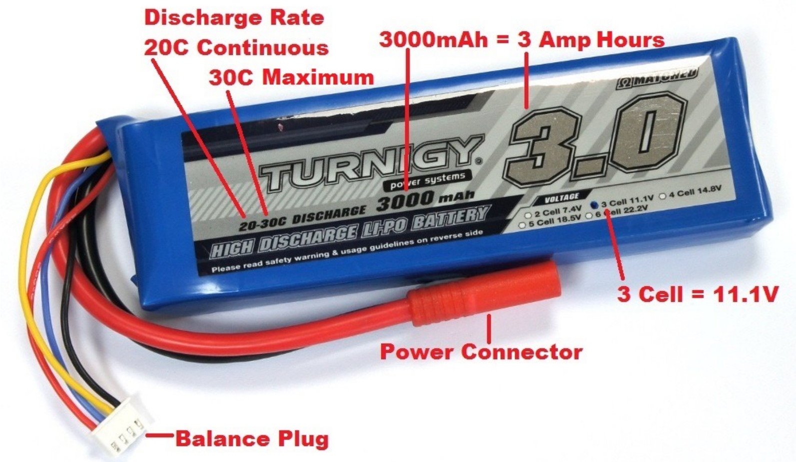


image credit: http://dronesarefun.com/BatteriesForUAV.html

image credit: Solar Copter, Queen Mary University

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Software Architecture

Quadrotor Platform

ESCs

Flight Controller

Radio Interface

Ground station control

SIMULINK

MAVLINK
MICRO AIR VEHICLE COMMUNICATION PROTOCOL

ROS
Open Source Robotics Foundation

An open-source, low overhead and low latency communication framework for sending and receiving messages from small UAVs

An open-source framework of C, C++ and/or Python libraries for robotics applications, primarily on Linux/UNIX - applicable to both arial and terrestrial robotics

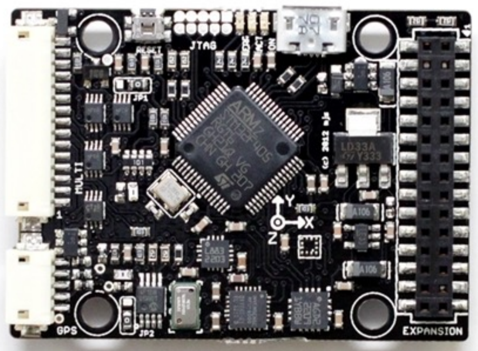
Flight Controller

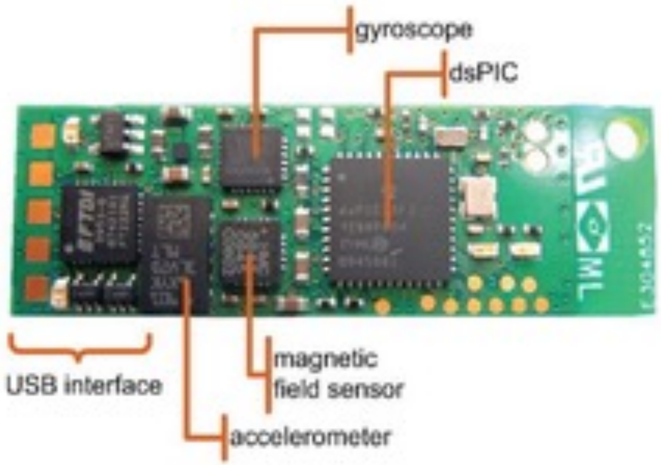
- Used to stabilize multi-rotor based on sensors, typically based on an inertial measurement unit (IMU).
- IMU contains accelerometers, gyroscopes, and magnetometer

Commonly used are Arducopter, Pixhawk and PX4FMU (+ AscTec AutoPilot - dual CPU)
with integrated IMU, processors and interfaces

pixHawk

PX4FMU





IMU developed by ETH,
PCB of ETHOS, the ETH orientation sensor CC 3.0

PIXHAWK

PIXHAWK is the industry standard autopilot, designed by the open hardware development team in collaboration with 3D Robotics and ArduPilot Group.

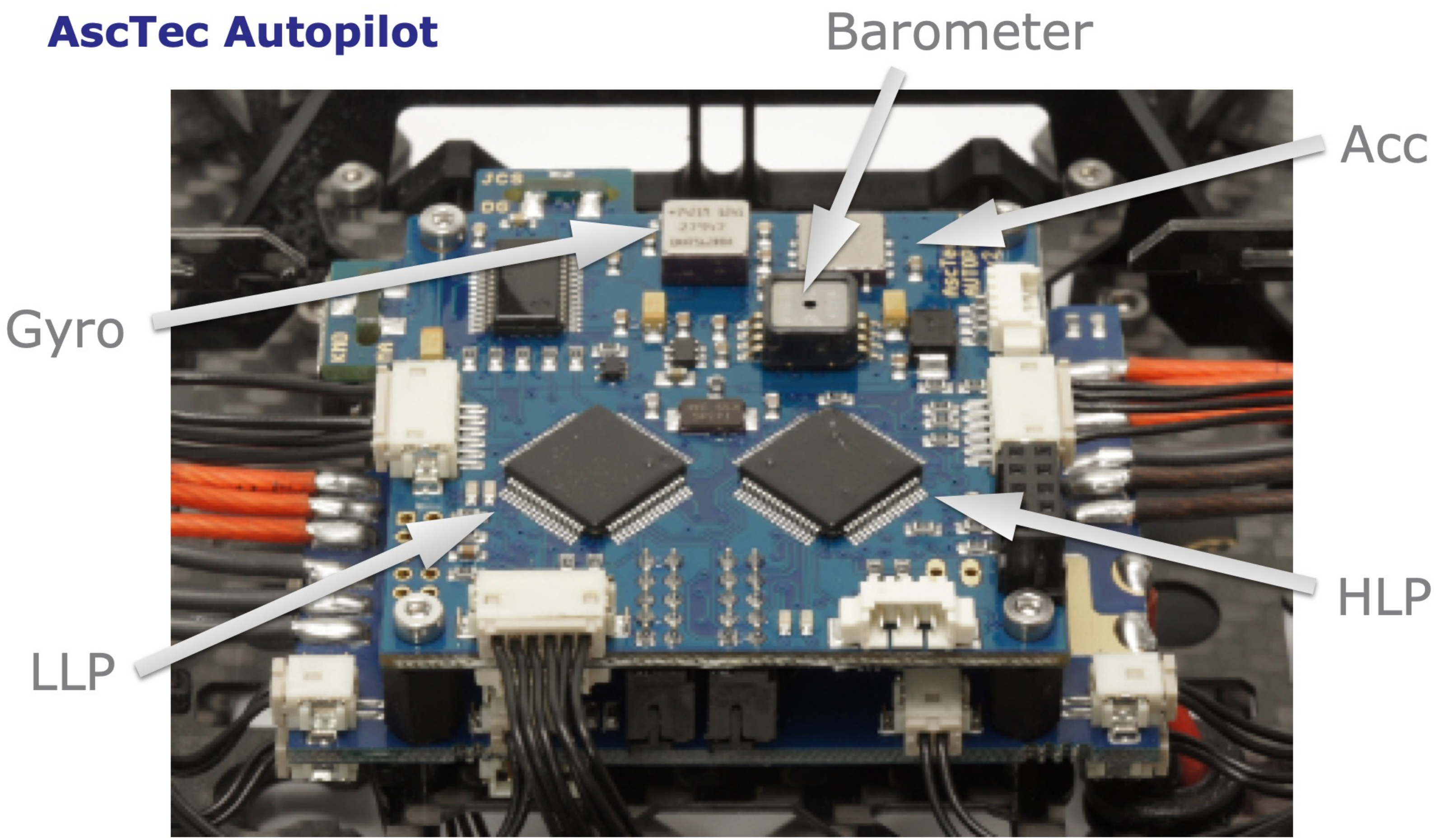
Processor
- 32-bit ARM Cortex M4 core with FPU
- 168 Mhz/256 KB RAM/2 MB Flash
- 32-bit failsafe co-processor

Sensors
- MPU6000 as main accel and gyro
- ST Micro 16-bit gyroscope
- ST Micro 14-bit accelerometer/compass (magnetometer)
- MEAS barometer

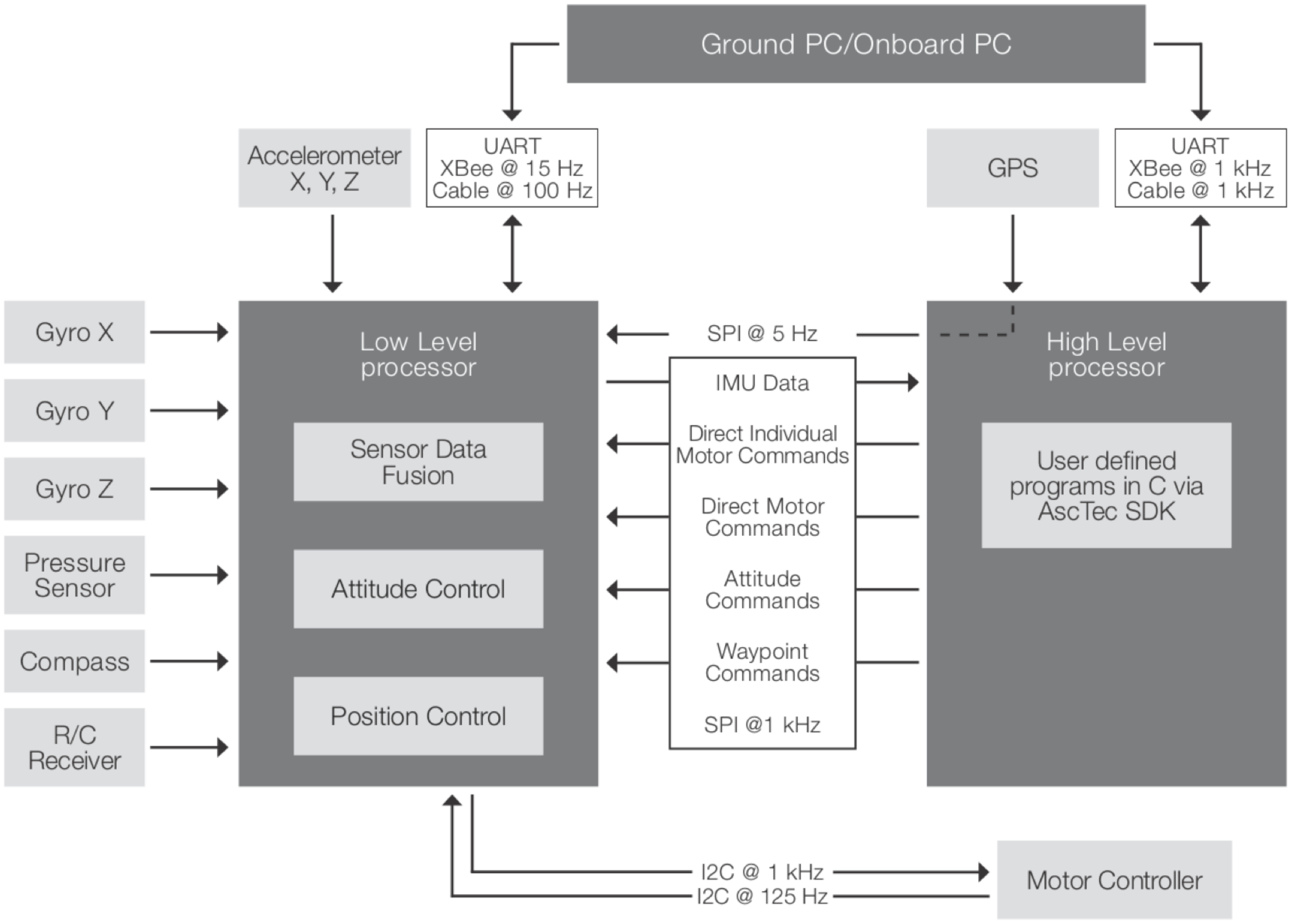
Power
- Ideal diode controller with automatic failover
- Servo rail high-power (7 V) and high-current ready
- All peripheral outputs over-current protected, all inputs ESD protected

Interfaces
- 5x UART serial ports, 1 high-power capable, 2 with HW flow control
- Spektrum DSM/DSM2/DSM-X Satellite input
- Futaba S.BUS input (output not yet implemented)
- PPM sum signal
- RSSI (PWM or voltage) input
- I2C, SPI, 2x CAN, USB
- 3.3V and 6.6V ADC inputs

Example: AscTec Autopilot



Example: AscTec Autopilot



Communication

- XBee or similar: small, low power (100mW), 250kbit/s and extremely low latency: good for real-time control in a **laboratory** setting

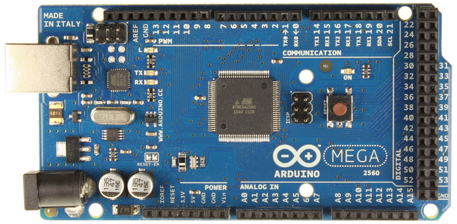
- 3D Robotics 915/433MHz radios, 100mW transmit power and UART connection for direct interfacing with supported platforms (eg. Pixhawk) via the **MAVLink** protocol.

- **Higher frequency** communications for higher-bandwidth applications, such as streaming real time video - often in the 5.8GHz band. More susceptible to noise and interference, but dramatically higher maximum throughout (protocol limited, but with 802.11ac 433Mbit/s is achievable per channel)

- Beyond a range of ~ 1 mile, wider-range solutions more appropriate -eg. GSM, satellite

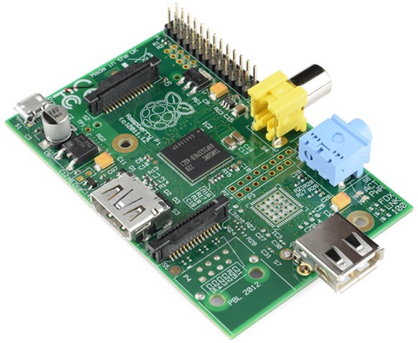
Powerful, lightweight or cheap - choose any two!

On-board Processing



Arduino Mega

8 -> 32 bit
Mass x 1.1
Cost x 1.1



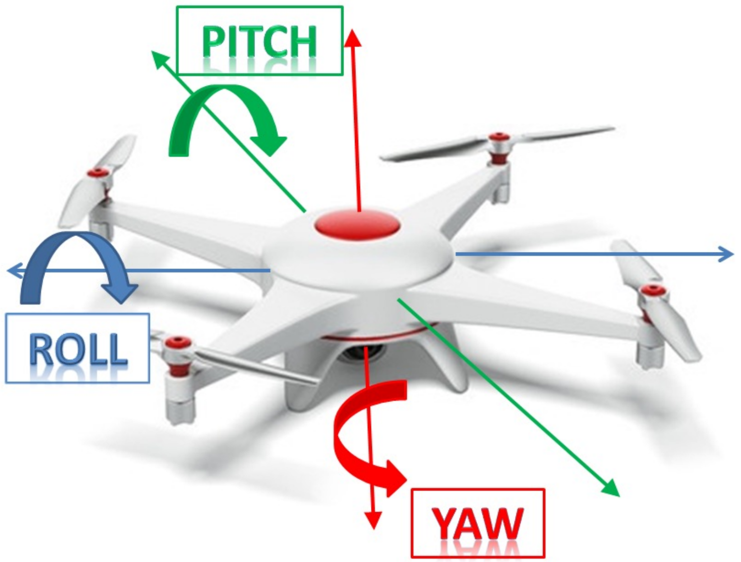
Raspberry Pi

FLOPS x 10
Mass x 5
Cost x 15

Intel NUC

Control of a multi-copter

Add more text. Move them before sensors.



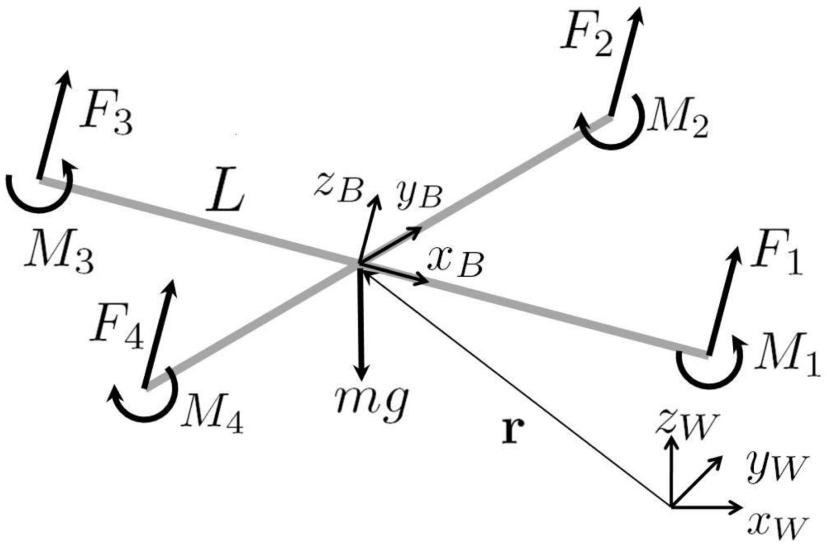


image credit: http://innovationclub.vn

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Control of a Rotorcrafts: quad-rotors

- Quadrotor control relies on varying the speed of individual propellers to generate differential thrust.
- **Pitch** is controlled by increasing speed on motors 1 and 2 while decreasing on 3 and 4, and vice versa.
- **Roll** involves motors 1 and 3 versus 2 and 4.
- **Yaw** is controlled by adjusting motor pairs 1 & 4 against 2 & 3
- Commanding all motors simultaneously controls **altitude**—higher speeds increase lift, while lower speeds reduce it.

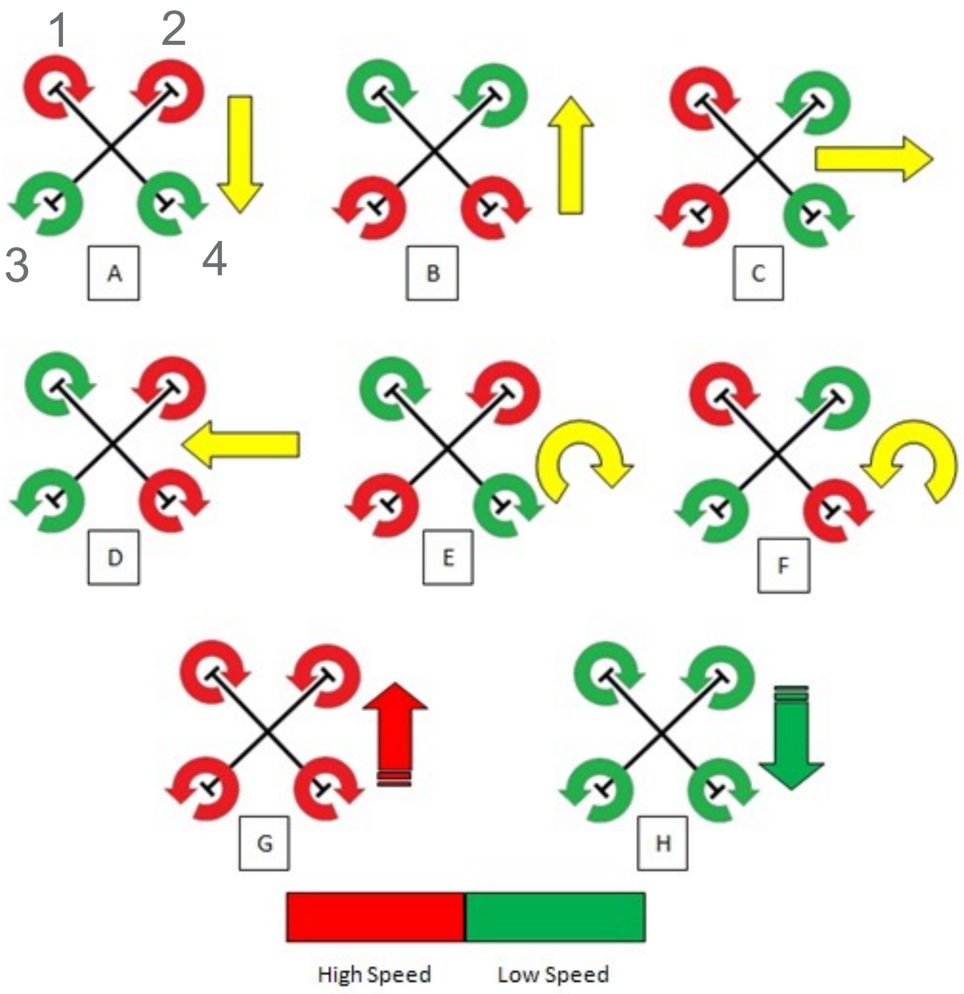


image credit: http://vueloartificial.com/

Control of multi-rotors

- A similar control strategy applies to other rotorcrafts, adjusted based on the **number** of propellers.
- In general, **more** propellers offer greater control authority and **degrees of freedom**, enhancing maneuverability.

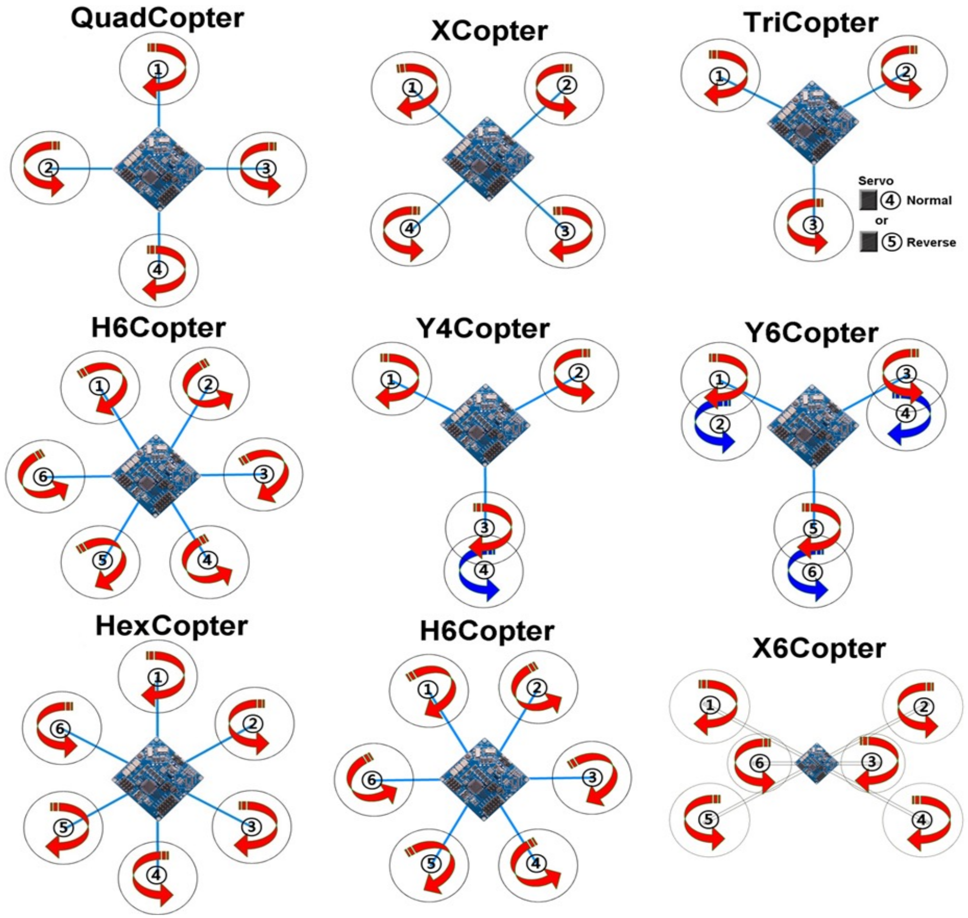
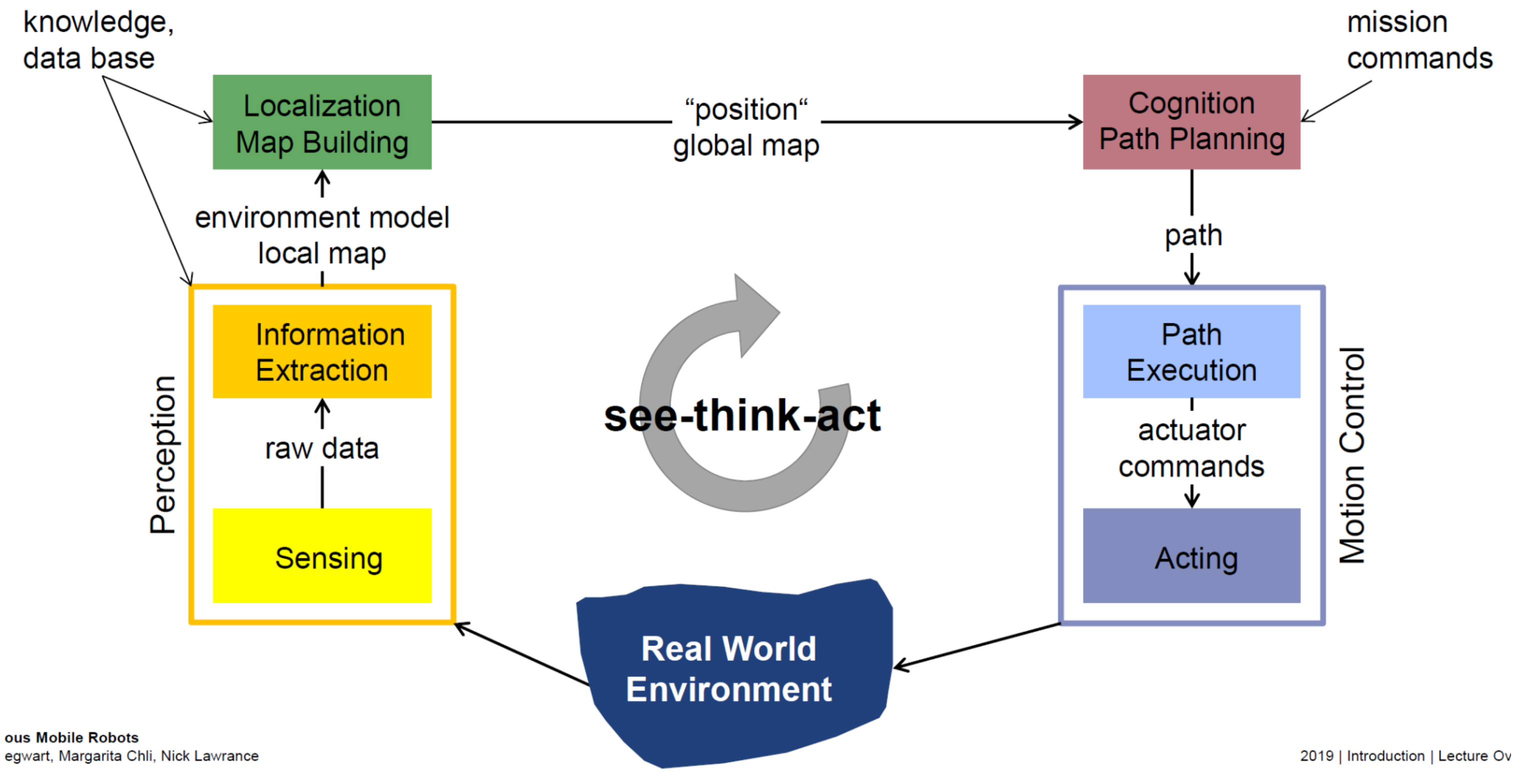


image credit: http://innovationclub.vn

Purpose of Sensors

Sensors are necessary to close the action-perception loop



A sensor is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument

Sensors

Distance perception
- Ultrasonic (Sound) ✅
- Laser (Light) ✅
- Height (e.g. pressure)

Inertial sensors
- Accelerometers ✅
- Gyroscope ✅
- Magnetometer ✅

Visual-based perception
- Camera ✅
- Optic Flow

https://www.discoverwildlife.com/animal-facts/what-is-echolocation

Distance Sensors: Pressure - Baromoter

- Air pressure drops with altitude
- $p \approx p_0 e^{-(h/7)}, p_0 =$ pressure at sea level
- Strain on a sealed gas container is measured

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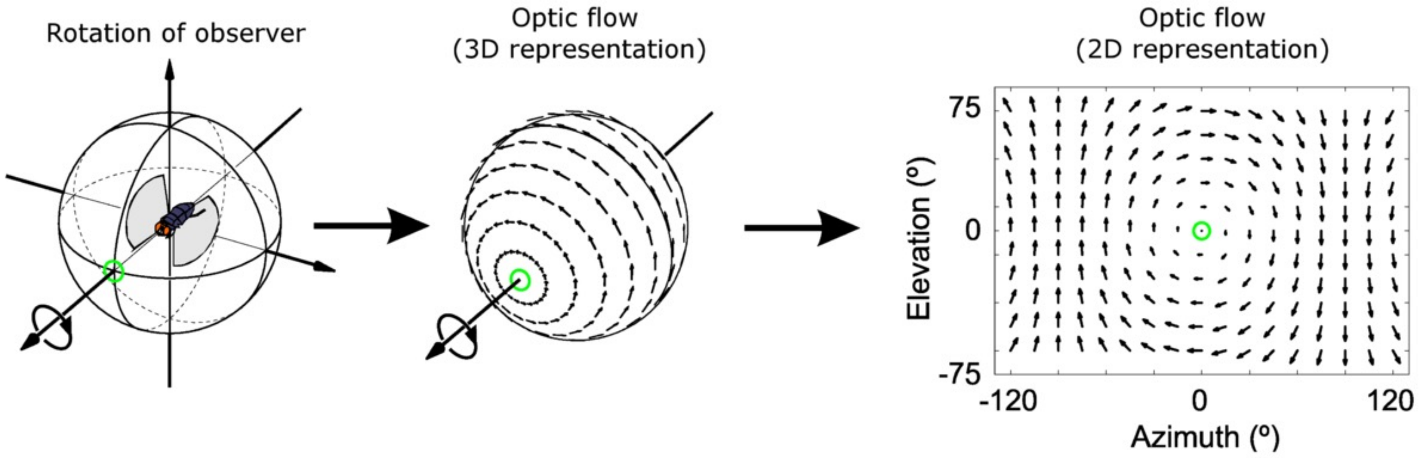
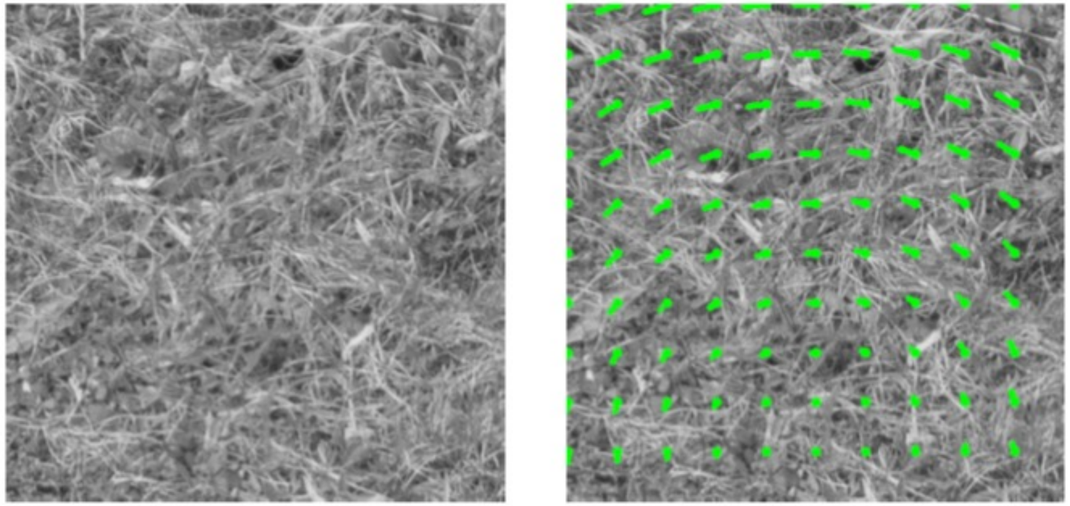
Distance Sensors: Pressure - Baromoter

- The air pressure depends on atmospheric conditions
- Only relative altitude change can be measured
- Slamming of doors, etc. affects the measurement
- Accuracy without external influences: <1m
- Used even in cars to compute the altitude dependent perfect air/petrol mix

Visual-based Sensors: Optic Flow



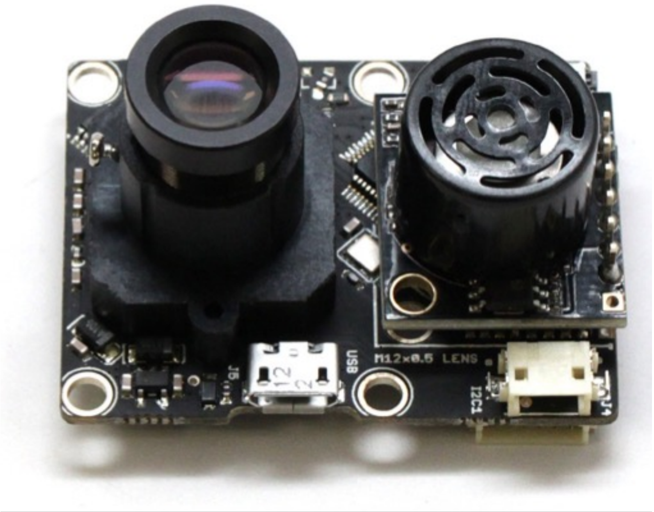


(a) first frame

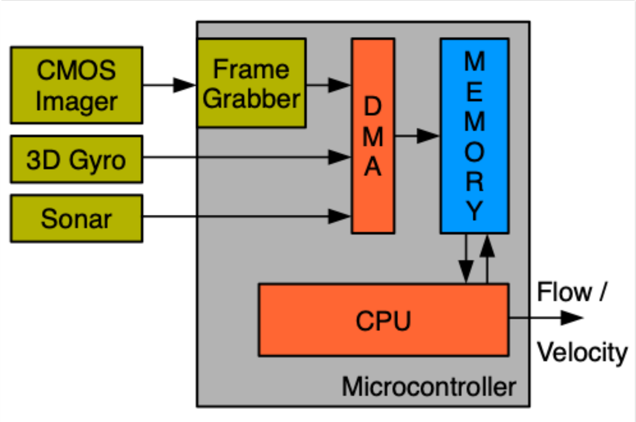
(b) second frame with the detected flow

Optic Flow

- Pix4Flow



	PX4FLOW
Size	45mm x 35mm
Power Consumption	115mA @ 5.0V = 0.575 W
Update Rate	250 Hz
Maximum Flow	± 1.5 rad/s = $\pm 86\,°/s$



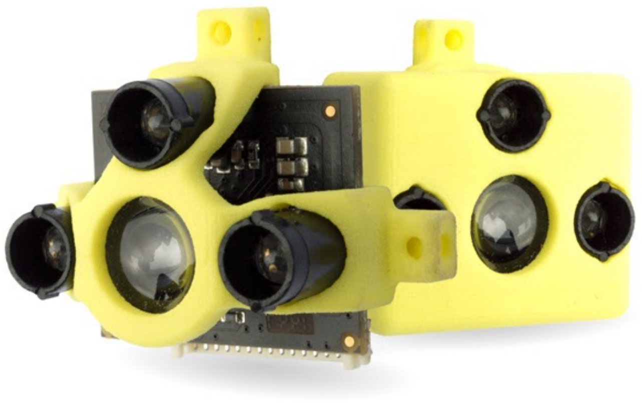
$$v_x = \frac{T_z x - T_x f}{Z} - \omega_y f + \omega_z y + \frac{\omega_x xy - \omega_y x^2}{f}$$

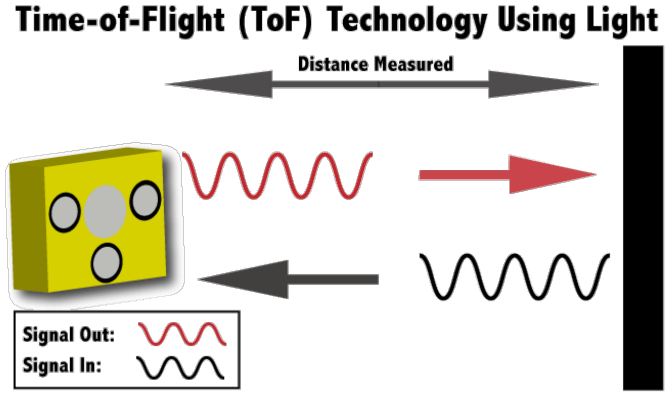
$$v_y = \frac{T_z y - T_y f}{Z} + \omega_x f - \omega_z x + \frac{\omega_x y^2 - \omega_y xy}{f}.$$

Optic flow algorithm: Sum of absolute differences (SAD) block matching algorithm

8x8 pixel block within a search area of ±4 pixels in both directions

Terraranger One

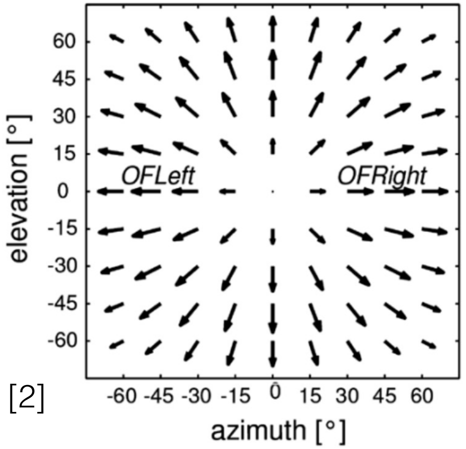




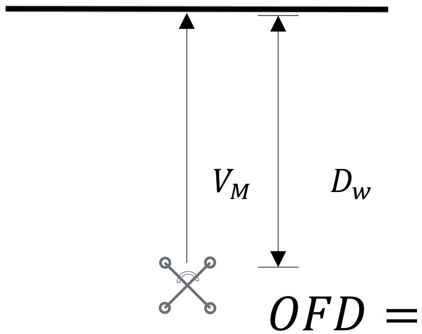
Principle:	Infrared Time-of-Flight (ToF)
Range:	Up to 14m indoors (At least 5 to 6m in sunlight)
Update rate:	1000Hz in fast mode (Up to 600Hz in precision mode)
Range resolution:	0.5cm
Accuracy:	± 4cm in precision mode
Field of view:	3°
Supply voltage:	12V DC recommended (10 to 20V DC accepted)
Supply current:	50mA average (110mA peak @12V)
Interfaces:	UART, +5V level, up to 115200,8,N,1. (Factory default when shipped)
	TWI (I2C compatible) +5V level (Firmware available on request)
Connector:	15 pin DF13 (open-ended cable provided)
Weight:	8g (Spider) or 10g (Box)

EPFL Empa

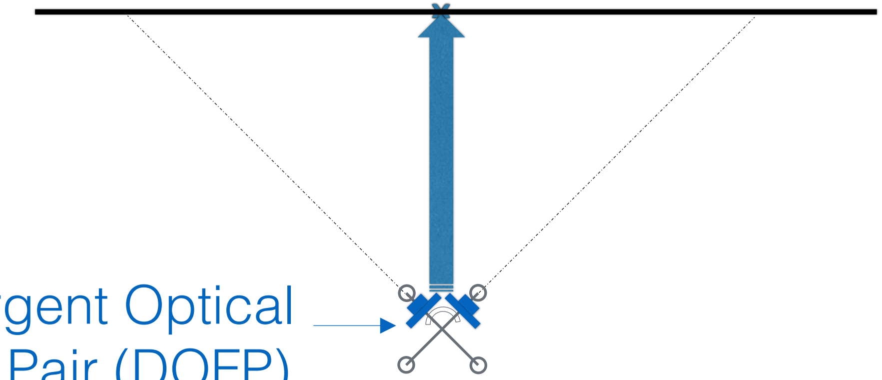
Bio-inspired Collision Avoidance



[2]



$$OFD = \frac{V_M}{D_w}$$



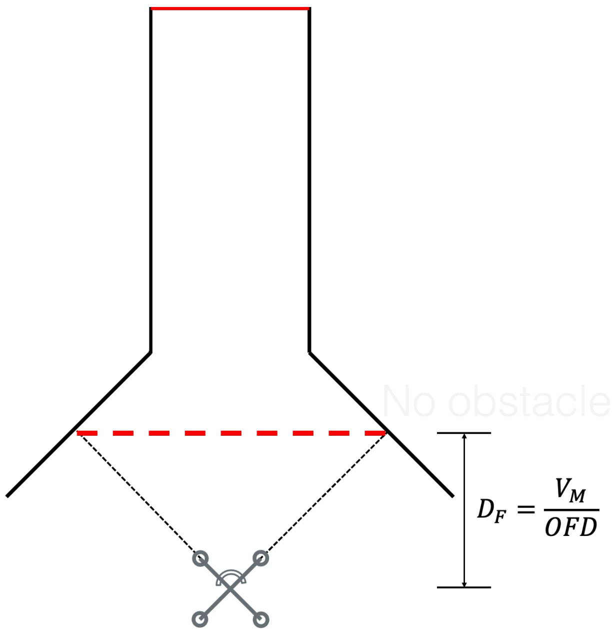
Divergent Optical Flow Pair (DOFP)

$$OFD = OFrate_{left} - OFrate_{right}$$

[1]Evangelista C, Kraft P, Dacke M, Reinhard J, Srinivasan MV (2010) The moment before touchdown: Landing manoeuvres of the honeybee Apis mellifera. J Exp Biol 213(2): 262–270
[2]J. C. Zufferey and D. Floreano, “Fly-Inspired Visual Steering of an Ultralight Indoor Aircraft,” IEEE Transactions on Robotics, vol. 22, no. 1, pp. 137–146, 2006.

Limitations

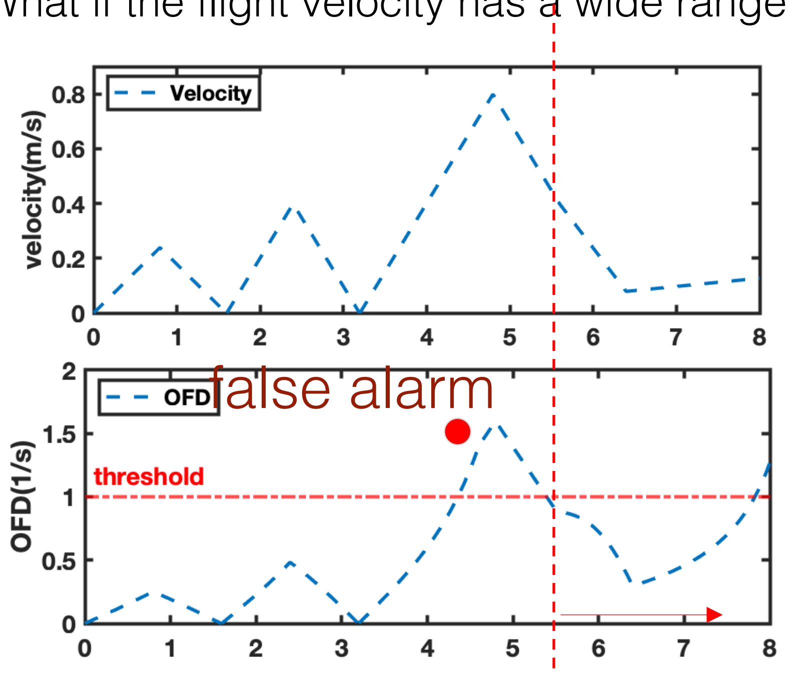
Obstacle



$$OFD = OFrate_{left} - OFrate_{right}$$

What is flying in a corridor?

What if the flight velocity has a wide range?

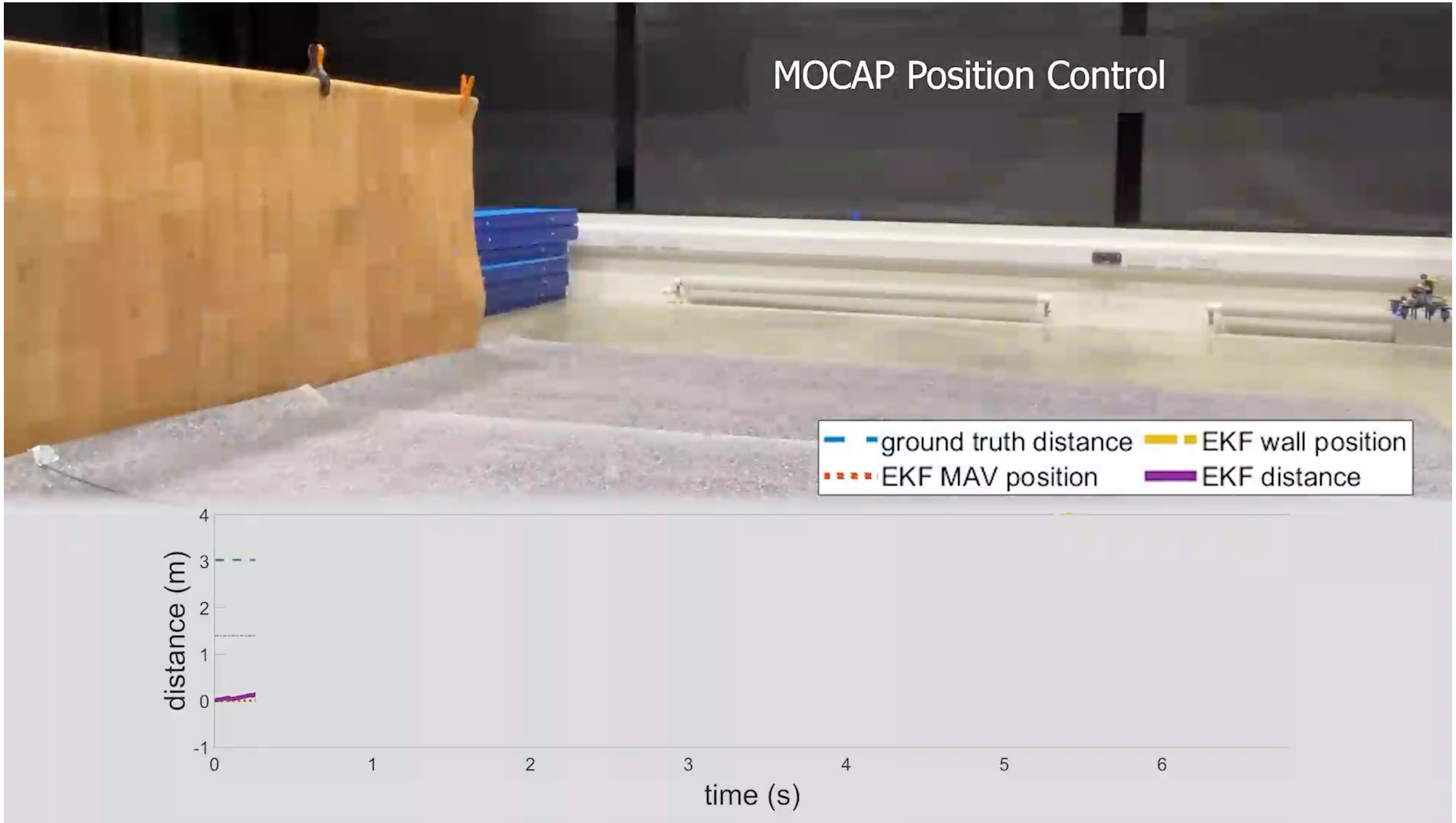


Seeing obstacle

Constant OFD threshold could give false alarm

Feng Xiao et al., *IEEE RA-L* 2021

Flight test results



Feng Xiao et al., *IEEE RA-L* 2021

Application: UAVs in agriculture

From 0:26

images courtesy of https://www.dji.com/mg-1 and https://www.techbubble.info/blog/drones-and-robotics/entry/worlds-largest-drone-manufacturer-dji-takes-on-the-agricultural-world

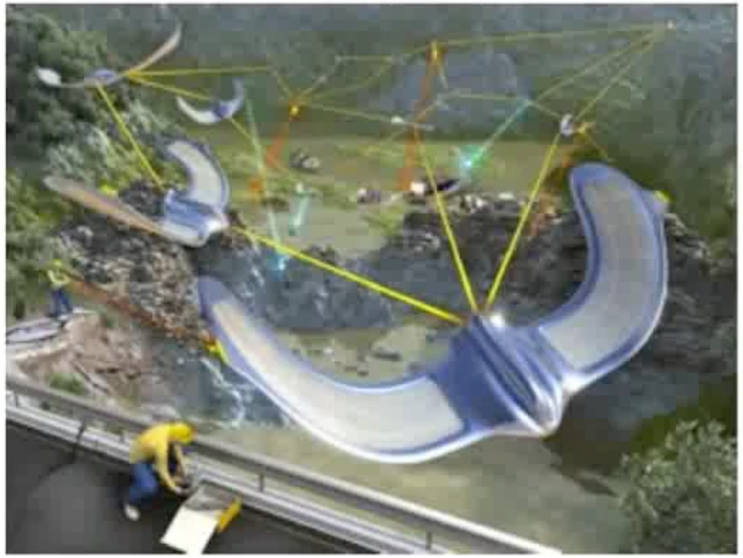
Application: Environmental mapping

Crop Management
- Countryside and Agriculture (with satellite monitoring)

(Ebee drone 2014) Video is courtesy of www.sensefly.com

Application: Search and rescue

Robust Acoustic Source Localization of Emergency Signals from Micro Air Vehicles



Meysam Basiri [1,2], Felix Schill[1], Pedro U.Lima[2], and Dario Floreano[1]

1. Laboratory of Intelligent Systems , EPFL, Switzerland
2. Institute for Systems and Robotics, IST, Lisbon, Portugal

http://lis.epfl.ch

Case study: UAVs in forest canopies

Forest canopies in rainforests, located 20–60 meters above ground, are vital habitats for many species and are increasingly under threat. Conventional data collection often relies on **hazardous** methods. **Robotics** offers an alternative solution for safe and sustainable canopy's sensing and sampling.

Single rope techniques (SRT) was the first generally used canopy access technique [1], beginning in the 1980s.

Autonomous Navigation and Mapping in Dense Forest [2],progressing in the 2020s.

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Lowman et al. *Plants, People, Planet,* 2021
Xiao, Feng, et al., IEEE RA-L 2021

Case study: UAVs in forest canopies

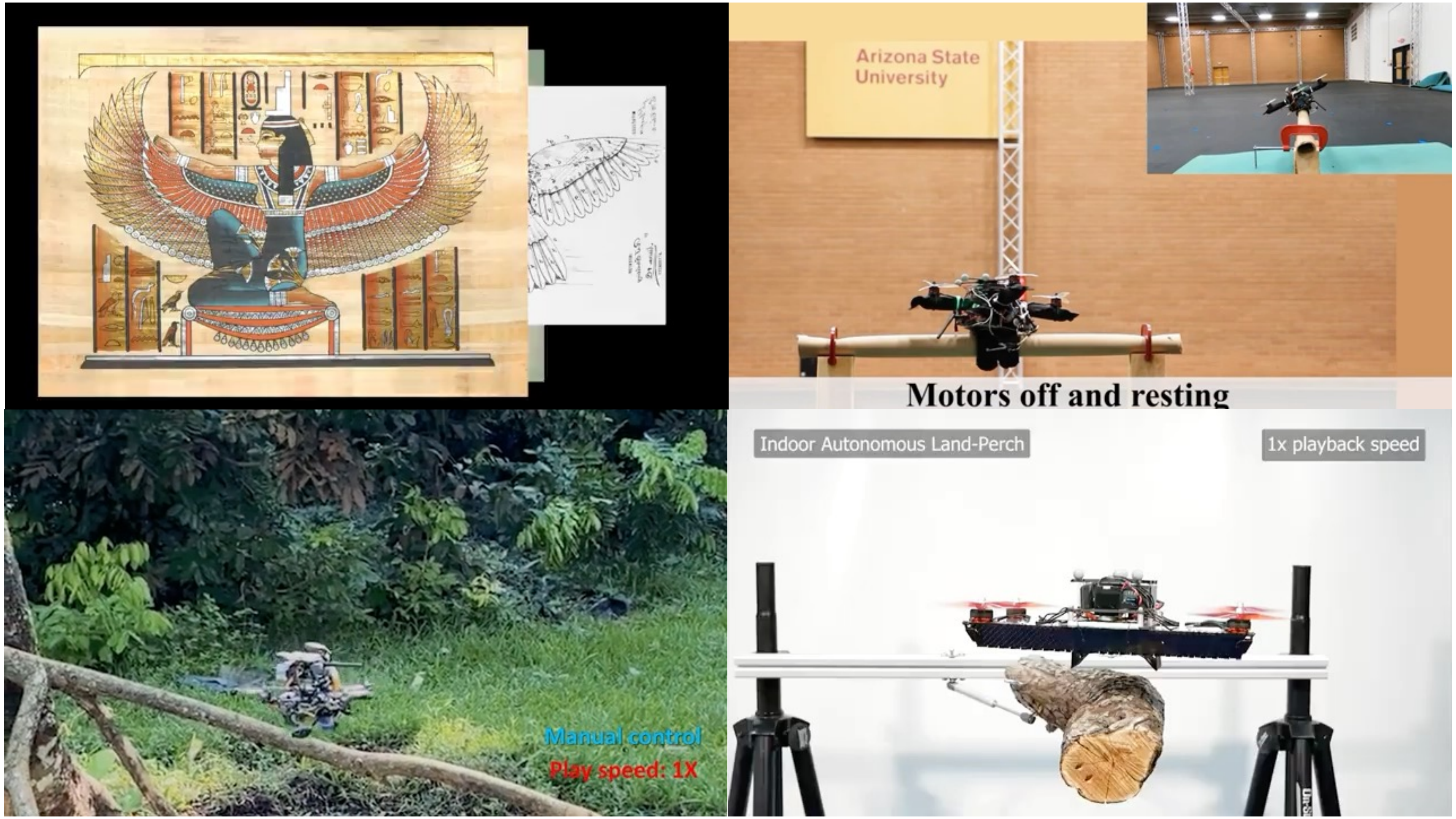
Example: Drone mapping of canopy. Reliable in avoiding contact and obstacles, but nature is scattered and unpredictable. Also, this method causes noise disturbance.

From 0:20

Xin Zhou et al., Sci. Robot (2022)

Case study: UAVs in forest canopies

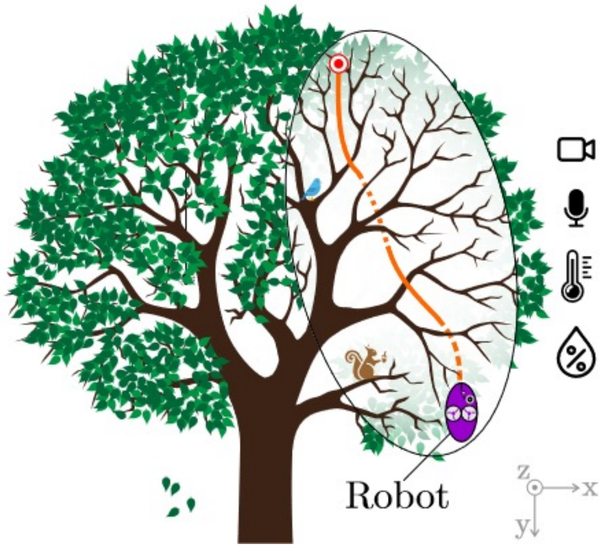
Example: Drone perching for energy savings and reduced noise.



Xin Zhou *et al.*,*Sci. Robot* (2022)
Zheng, P. *et al.*, *Nature Sci Rep* (2023)
Zheng L et al., IEEE RA-L 2024
Nguyen, P. H.et. al., *Soft robotics*, *2023*

Case study: UAVs in forest canopies

Example: Tethered robots for minimal invasive sensing.



Energy efficient and **reduced** environmental disturbance. However, precise control is needed.

How to tether **perch** without human intervention?

Kirchgeorg et al., IEEE T-RO, 2024

Case study: UAVs in forest canopies

Example: Tether perching using drones.

It enables shape and material **adaptability** with minimal actuation, low noise, and disturbance. However, upside-down **takeoff** is challenging, and the counterweight may strike the tether.

Hauf, F. et al., ICRA 2023.

Case study: UAVs in forest canopies

Aerial-deployed environmental pod by tether-perching on branch

Lan* and Romanello* et al., IEEE ICRA, 2024

Case study: UAVs in forest canopies

Aerial-deployed environmental pod by tether-perching on branch

1. Perching using drone

Lan* and Romanello* et al., IEEE ICRA, 2024

Case study: MEDUSA

Motivation: conventional water sampling systems require the use of human intervention or big underwater vessels to be deployed, which tend to disrupt the environment and affect the collection of clear data.

https://fishbio.com/heres-the-buzz-a-fish-sampling-technique-that-will-shock-you/

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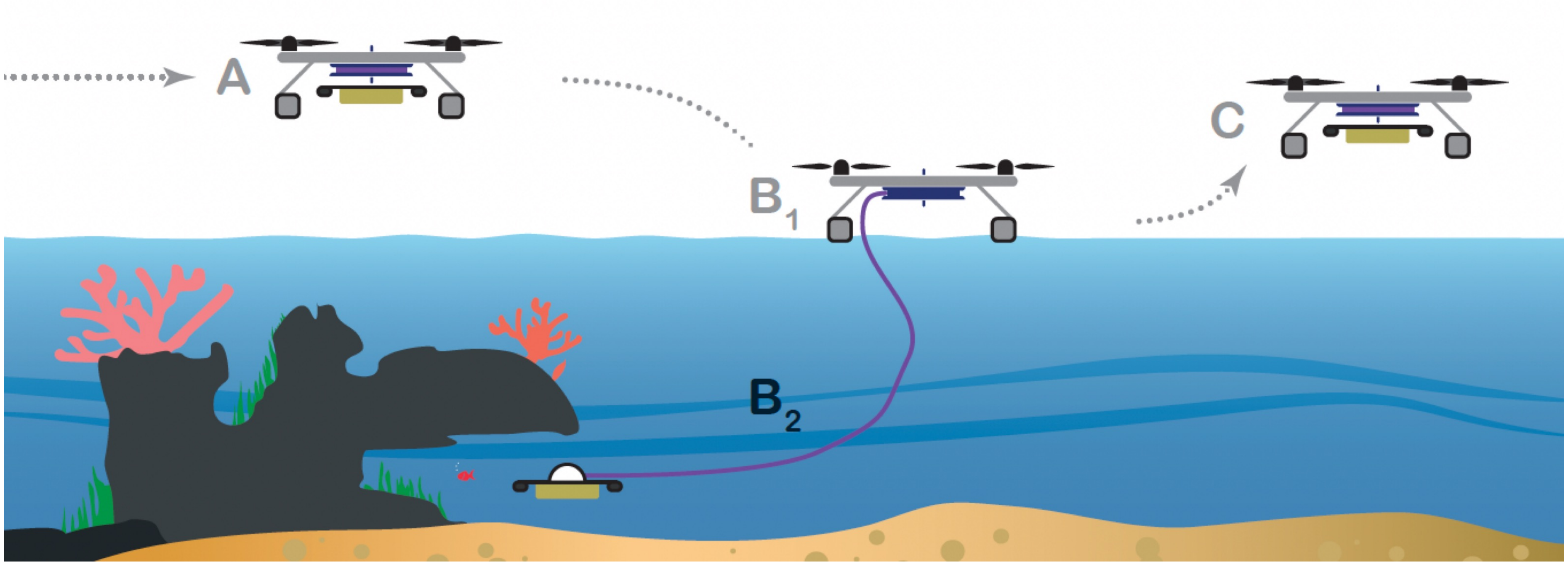
Galloway et al., Soft Robotics, 2016

Case study: MEDUSA

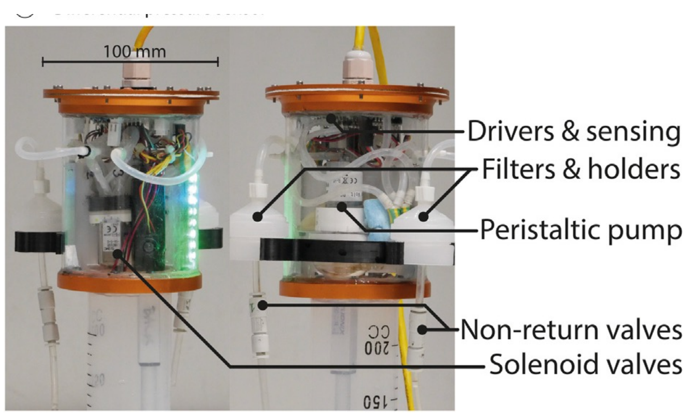
Aerial deployment helps reduce disturbance and enables operation in extreme environments. **Medusa's mission profile**: the drone flies to the target area and lands on water. It then deploys the tethered pod for the underwater mission. After completion, the pod is retrieved, and the drone proceeds to the next site or returns to land.

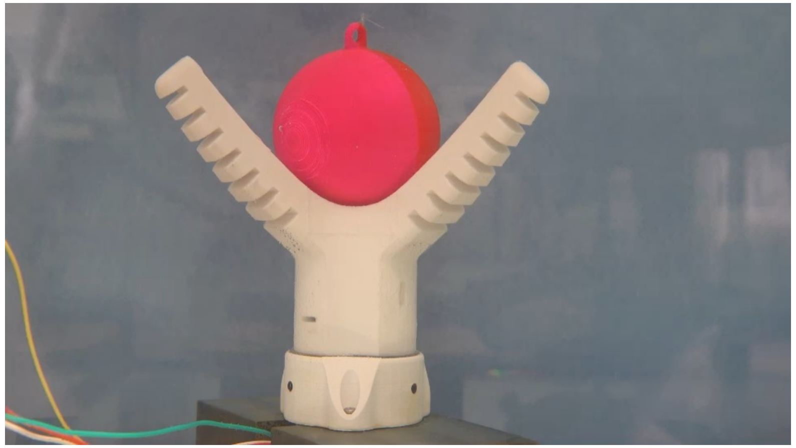


Debruyn et al., IEEE RA-L, 2020

Case study: MEDUSA

The system has been demonstrated both with a **water sampling** pod and with a **grasper**, collecting specimens and water samples to be analyzed.





Farinha et al. Frontiers in Environmental Science, 2023
Romanello et al., IEEE Robosoft, 2024

Learning goals

- Outline the rotorcraft platform's features:
  - *Types, Control, Components*
- Understand common sensors employed in drones.
  - *Barometric, IMU and Optic Flow*
- Discuss a few applications of drones, including two use case scenarios.
  - *Agriculture and in-canopy robots, MEDUSA*