CentraleSupélec

C 1.1 Introduction to quadrotors

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Introduction

Quadrotors: a great tool for teaching robotics

Nonlinear dynamics … but can be linearized near hovering

Underactuated … not all degrees of freedom are of interest

Different levels of modeling … depending on goal

Strong and complex disturbances … weak and simple at low speed

Varying parameters … can be considered invariant in a restrained flight envelope

…

Also: They are cool

Quadrotors applications

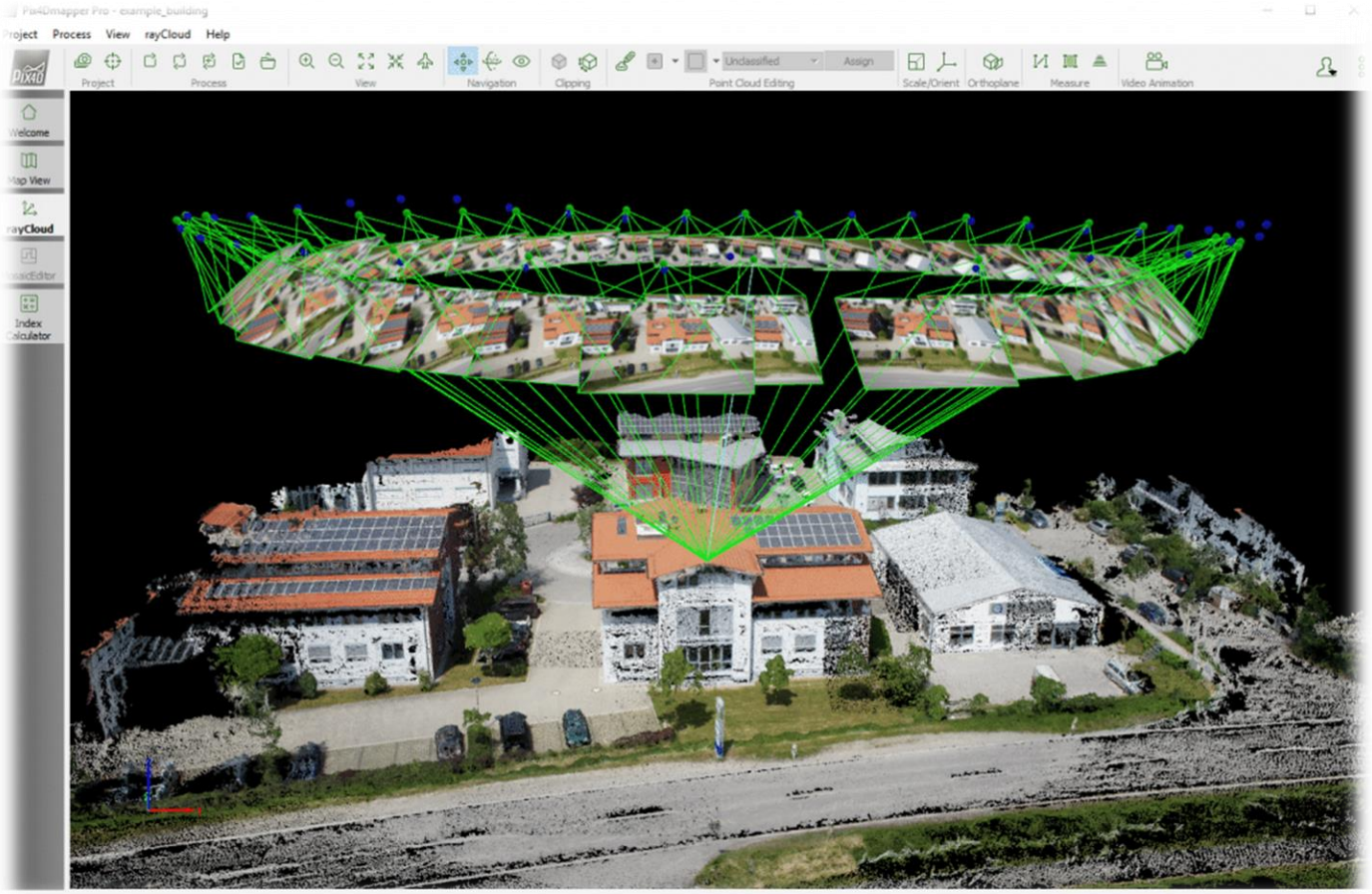
Quadrotors: a great tool for professionals

Cinematography

Quadrotors applications

Quadrotors: a great tool for professionals

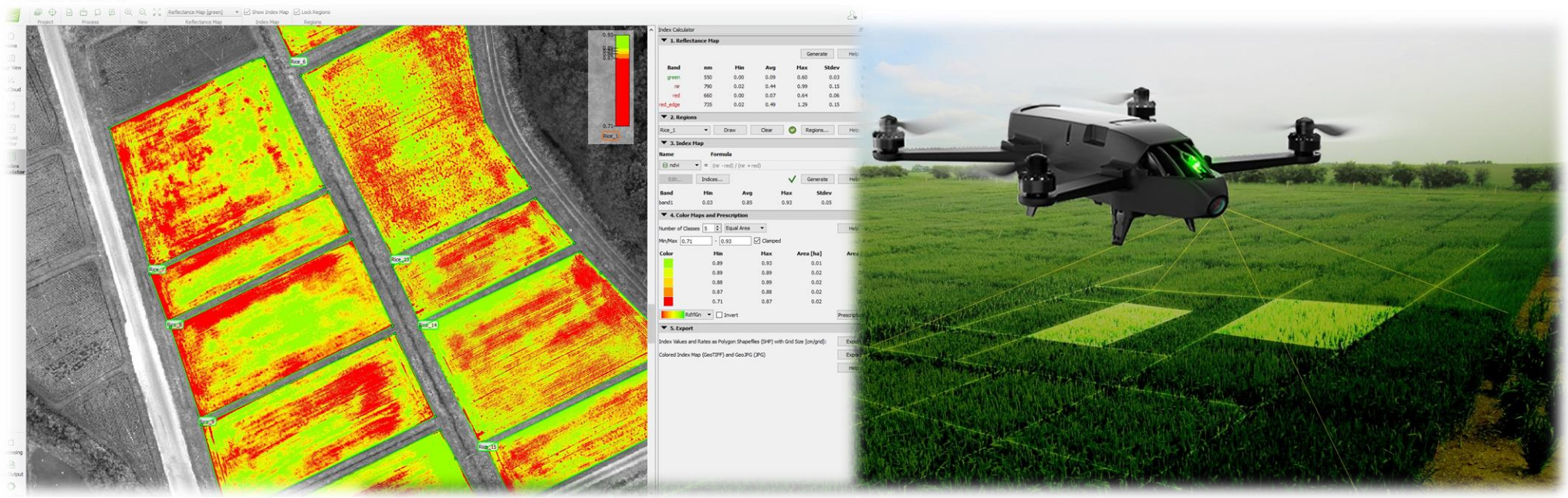
Photogrammetry



Quadrotors applications

Quadrotors: a great tool for professionals

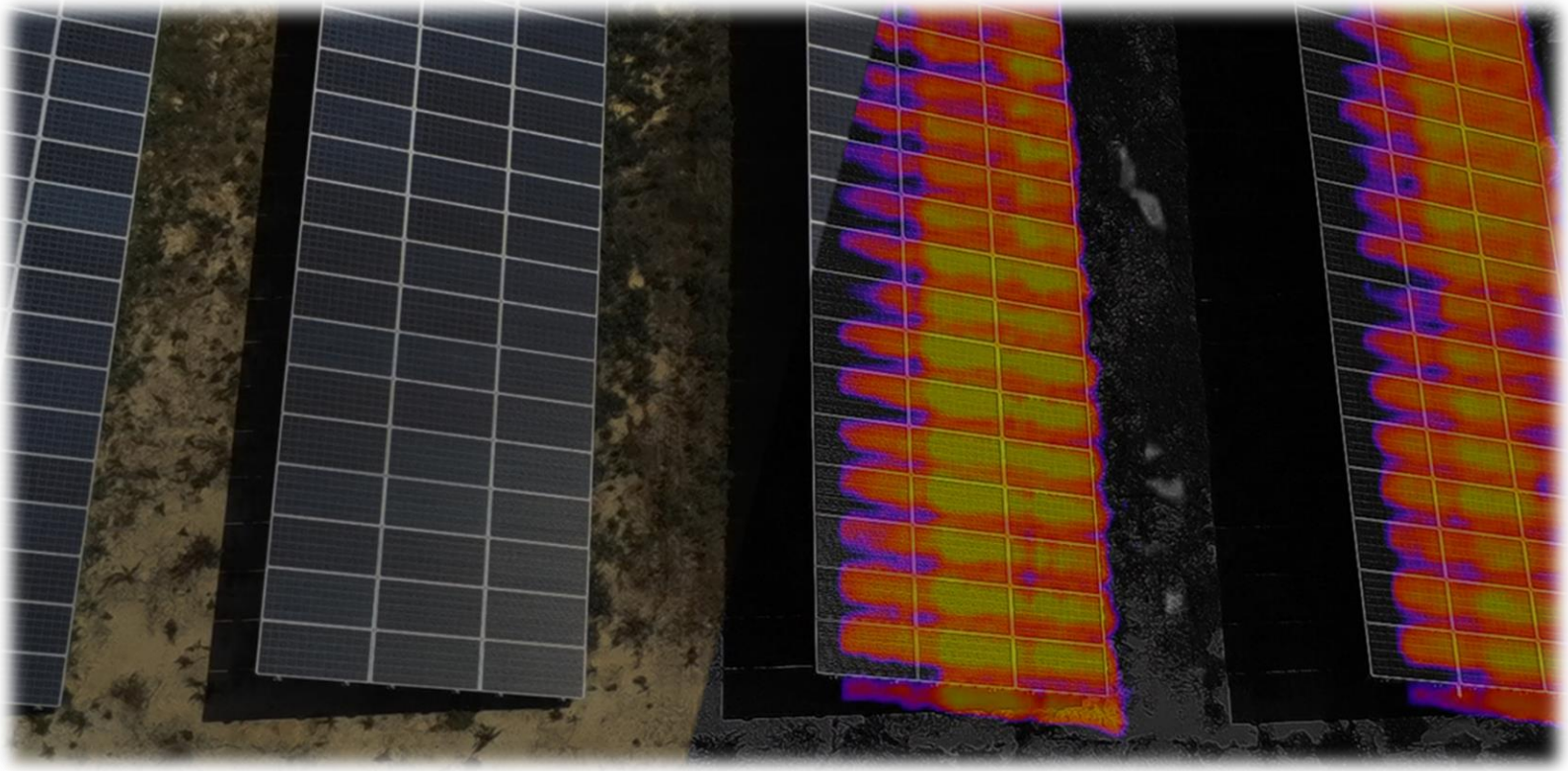
Agriculture



Quadrotors applications

Quadrotors: a great tool for professionals

Inspection



Vocabulary

Drone

- Initially: Unmanned radio-controlled fixed wing aircraft used as gunnery target
- Now: vague word designating any flying (or not) unmanned vehicle

UAV

Unmanned Aerial Vehicle

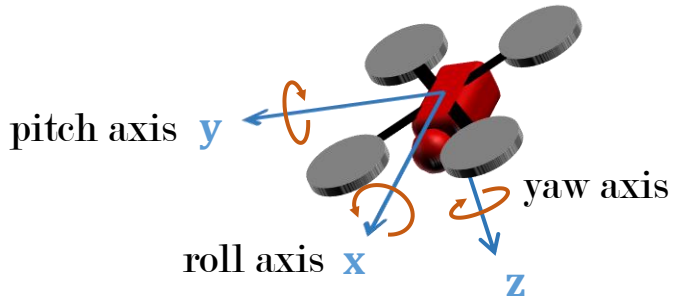
Quadrotor

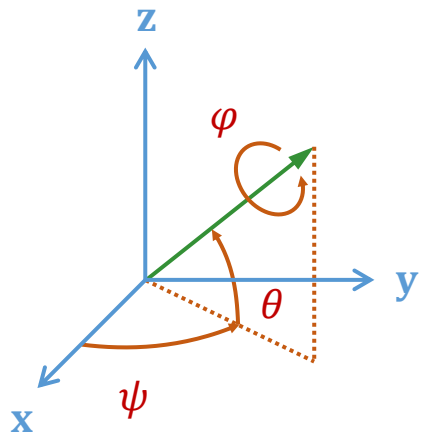
A rotary wing aircraft with four rotors

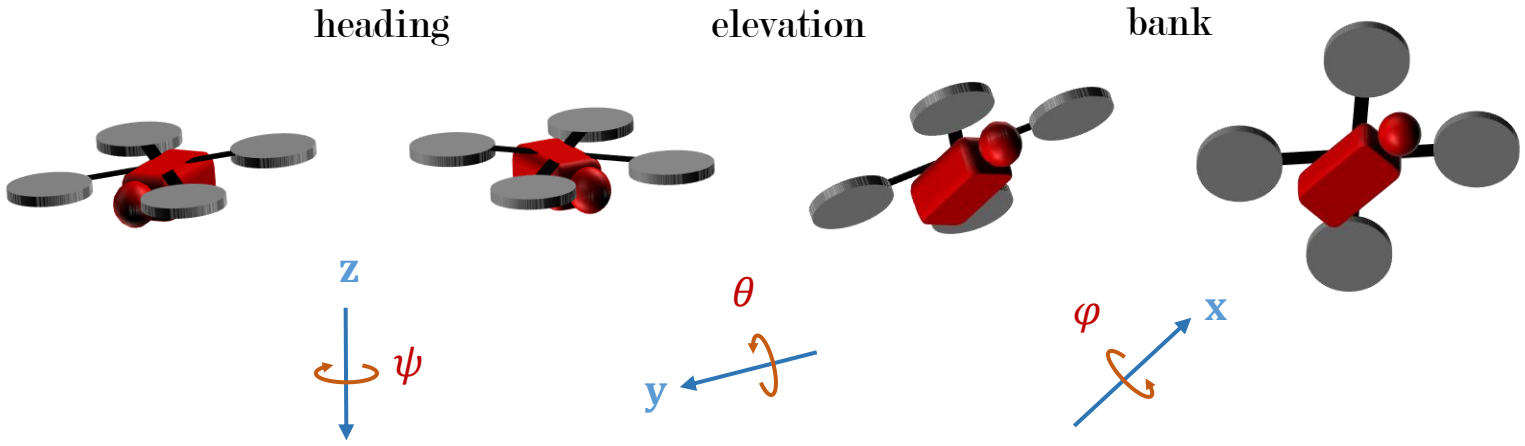
Vocabulary

Yaw, pitch and roll

Rotations along the vertical, lateral and longitudinal axes



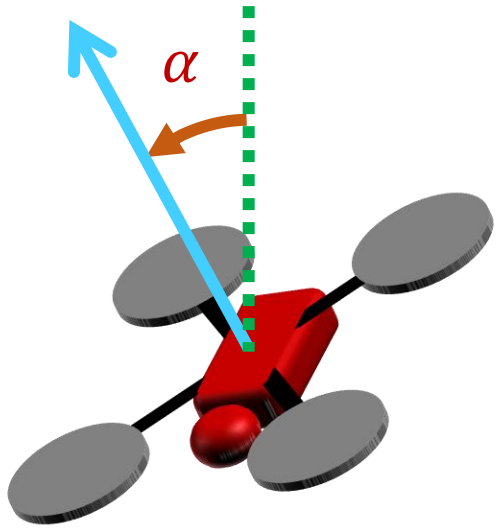




Vocabulary

Ground angle/horizontal tilt/thrust angle

Angle between the vertical of the drone and the vertical of the ground

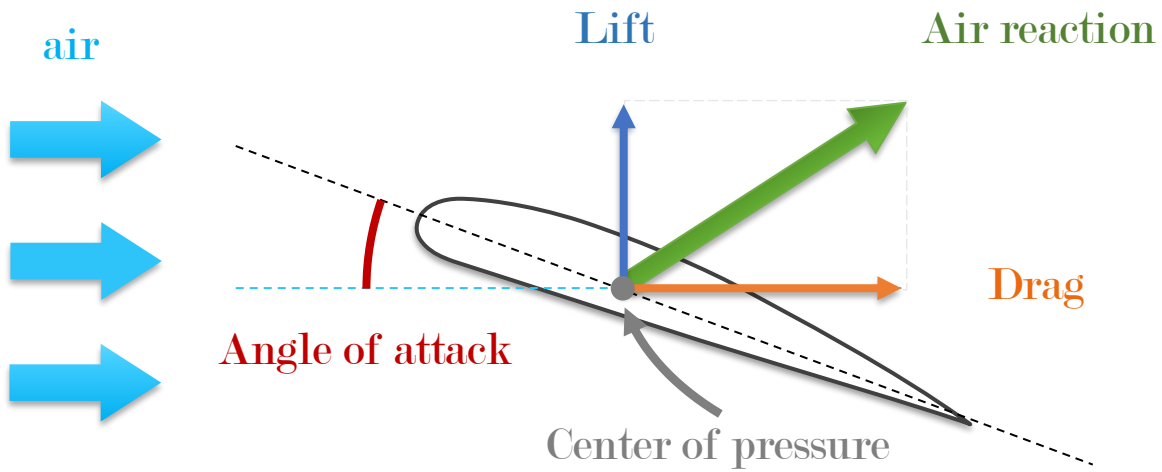


Vocabulary

Air speed / air velocity
Speed/Velocity relatively to its surrounding air mass

Angle of Attack (AoA)
Angle between a reference line of a body and its air velocity

Lift and Drag
Resultant of the aerodynamic actions applied on the *center of pressure*, projected onto the air velocity (drag) and its normal (lift)



Quadrotor actuation

Actuators

4 Propellers

- **Usually brushless DC motors**

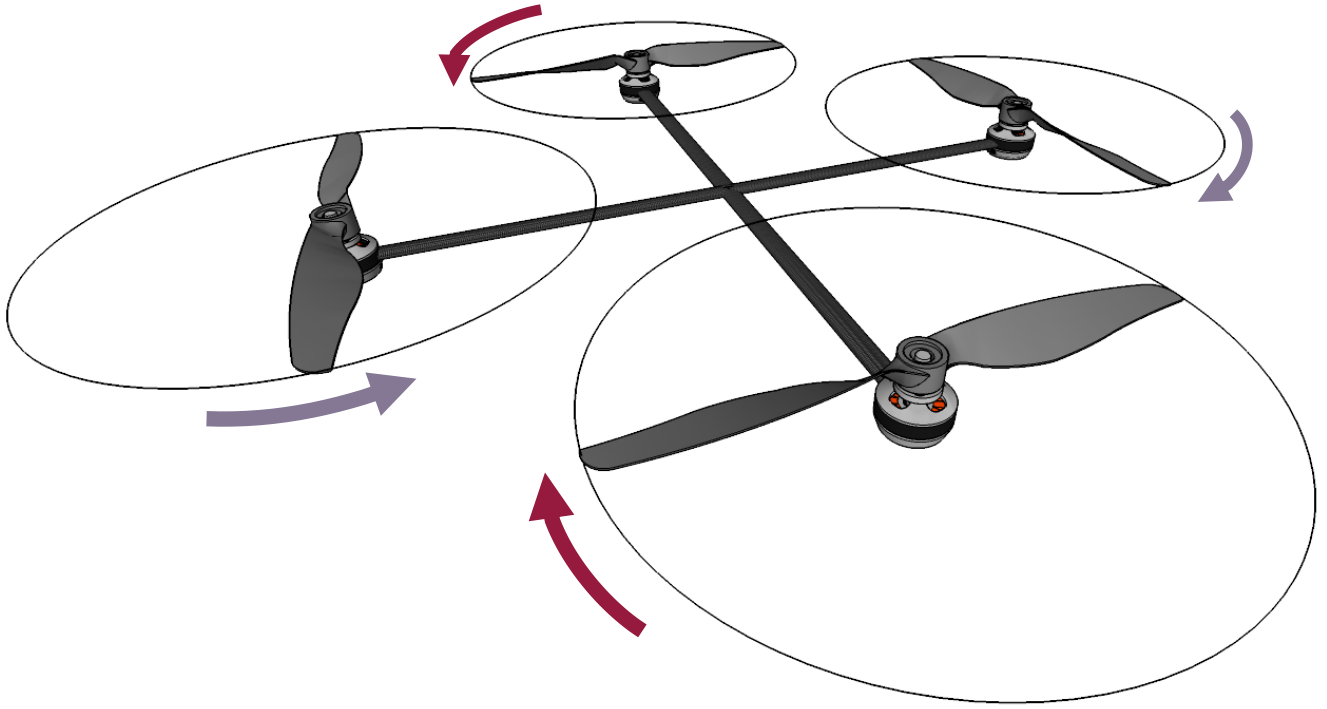
Quadrotor actuation

X4 quadrotor

4 propellers

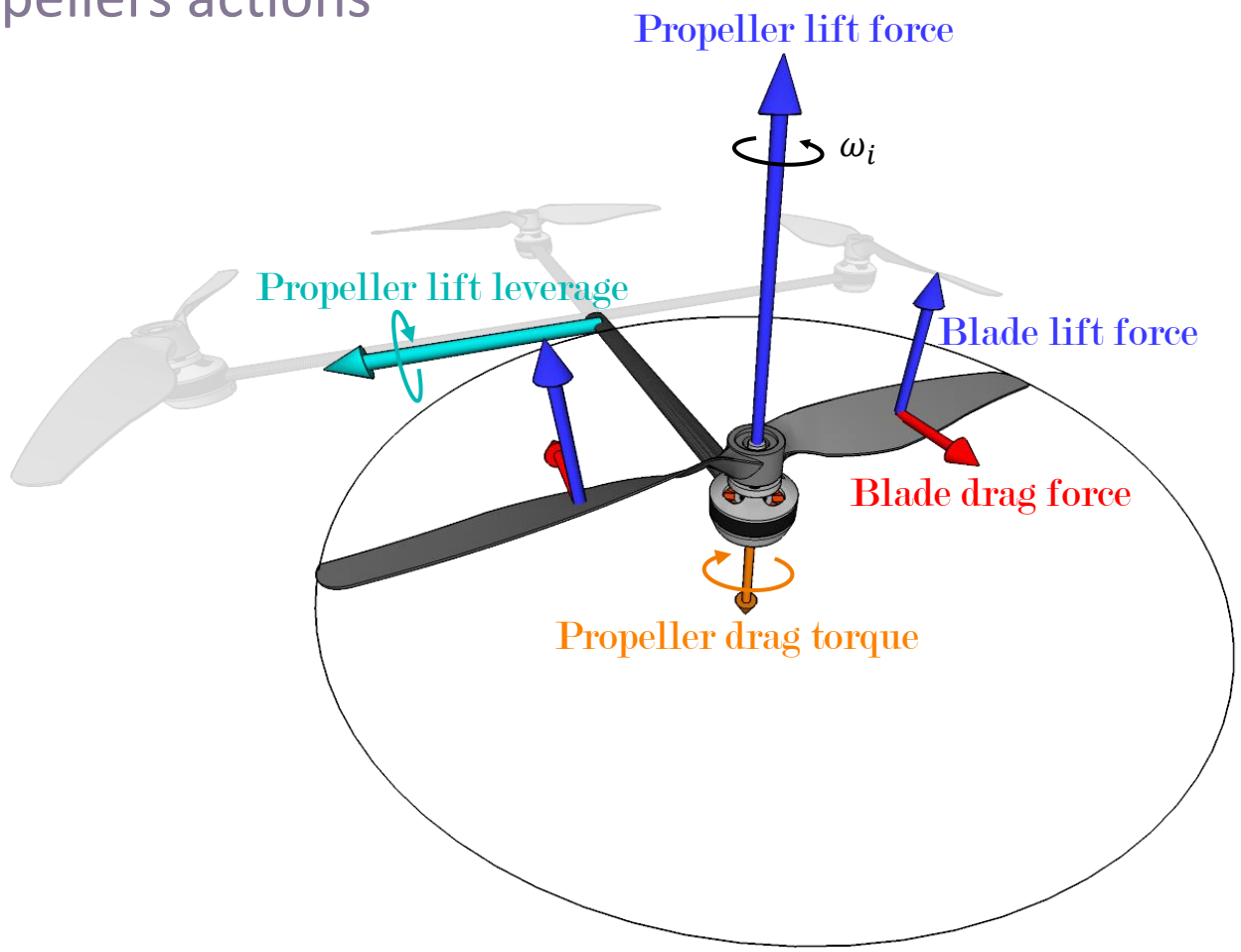
Vertical propellers axes

Alternate clockwise & anti-clockwise



Quadrotor actuation

Propellers actions



Forces

- Thrust (lift)

Torques

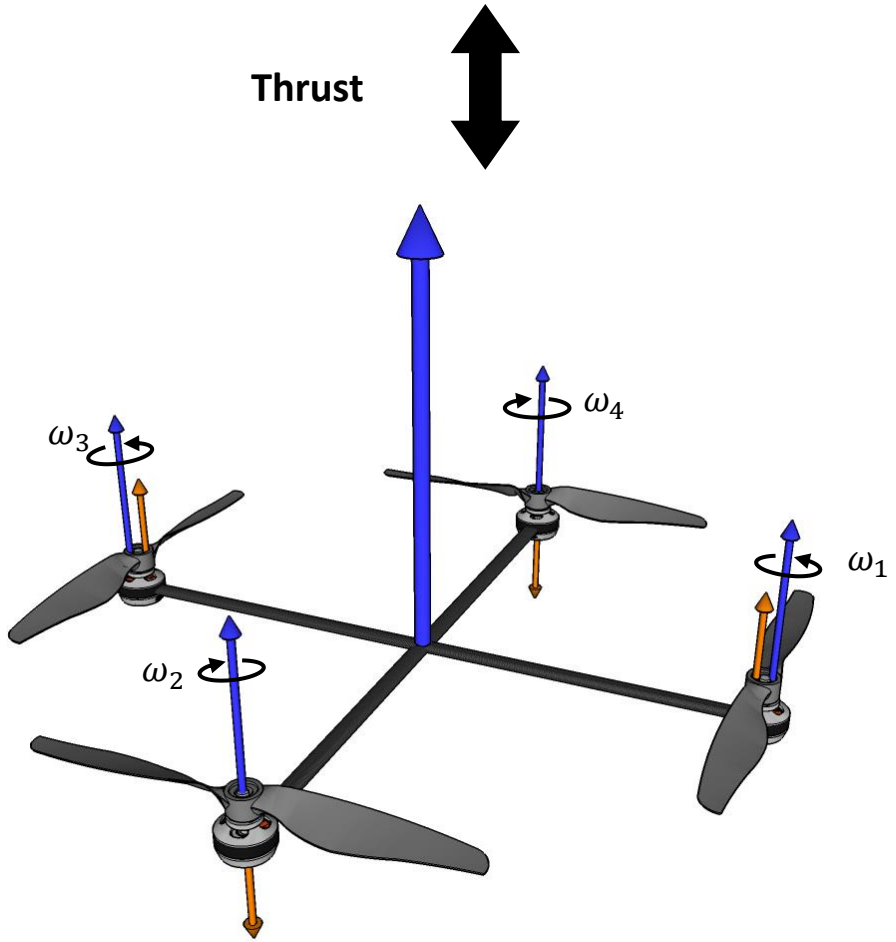
- Drag torque
- Lift leverage
- Reaction
- Gyroscopic

Quadrotor actuation

Vertical translation actuation

Collective thrust

Compensation of drag and lift torques



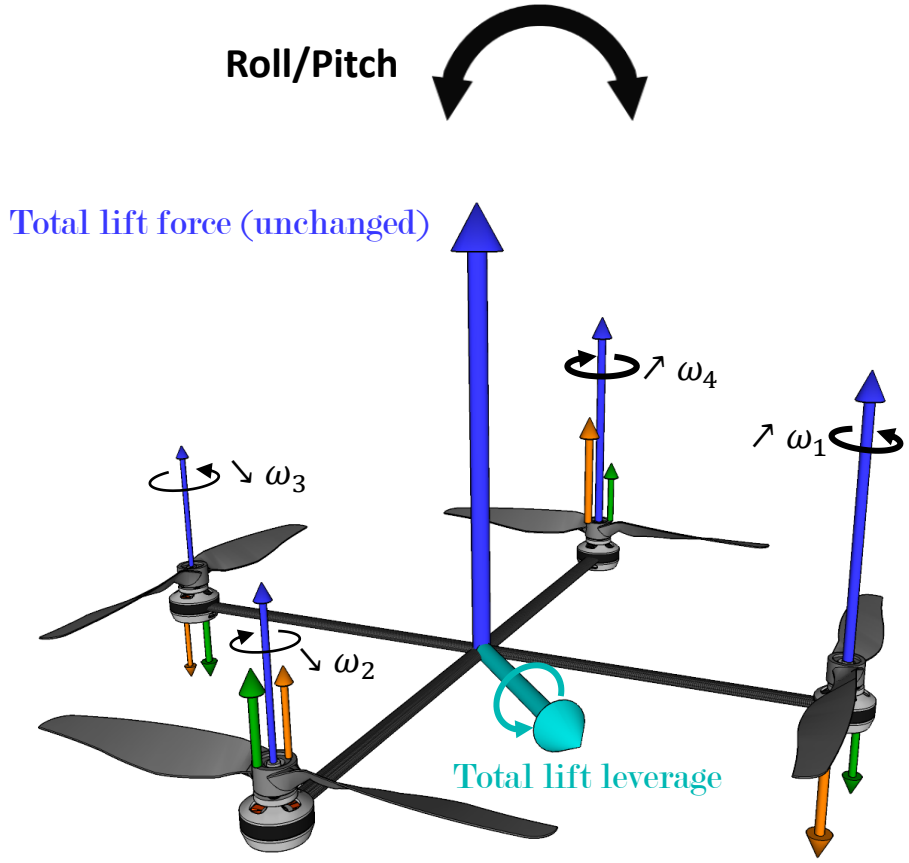
Quadrotor actuation

Roll and pitch actuation

Collective thrust unchanged

Asymmetry of lifts (leverage)

Compensation of drag torques



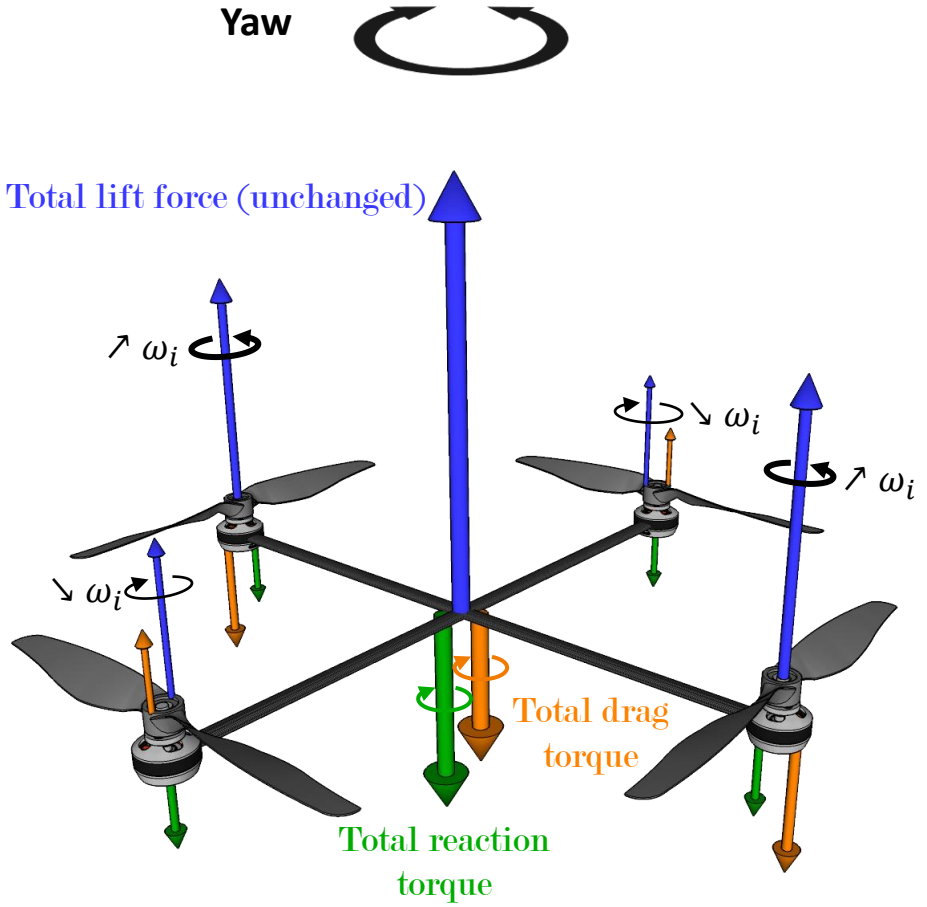
Quadrotor actuation

Yaw actuation

Collective thrust unchanged

Compensation of lifts torques

Drag torques unbalanced



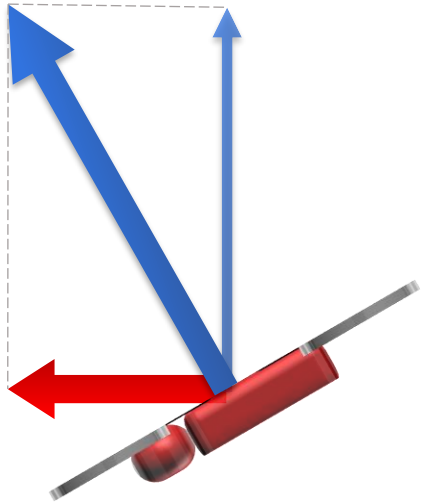
Quadrotor actuation

Underactuated system

6DOF vs 4 actuators

X and Y translation not directly actuated (in first approx.)

Use rotation and translation couplings



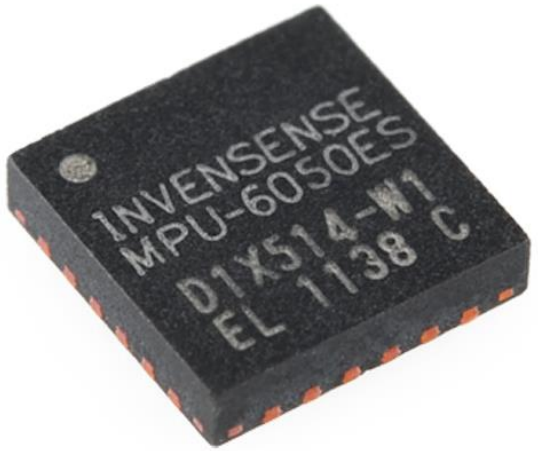
Quadrotor sensors

Inertial measurement unit (IMU)

Accelerometer
Aceleration / inertial frame (actually free fall deviation)

Gyrometer
Angular velocity / inertial frame

Proprioceptive sensors



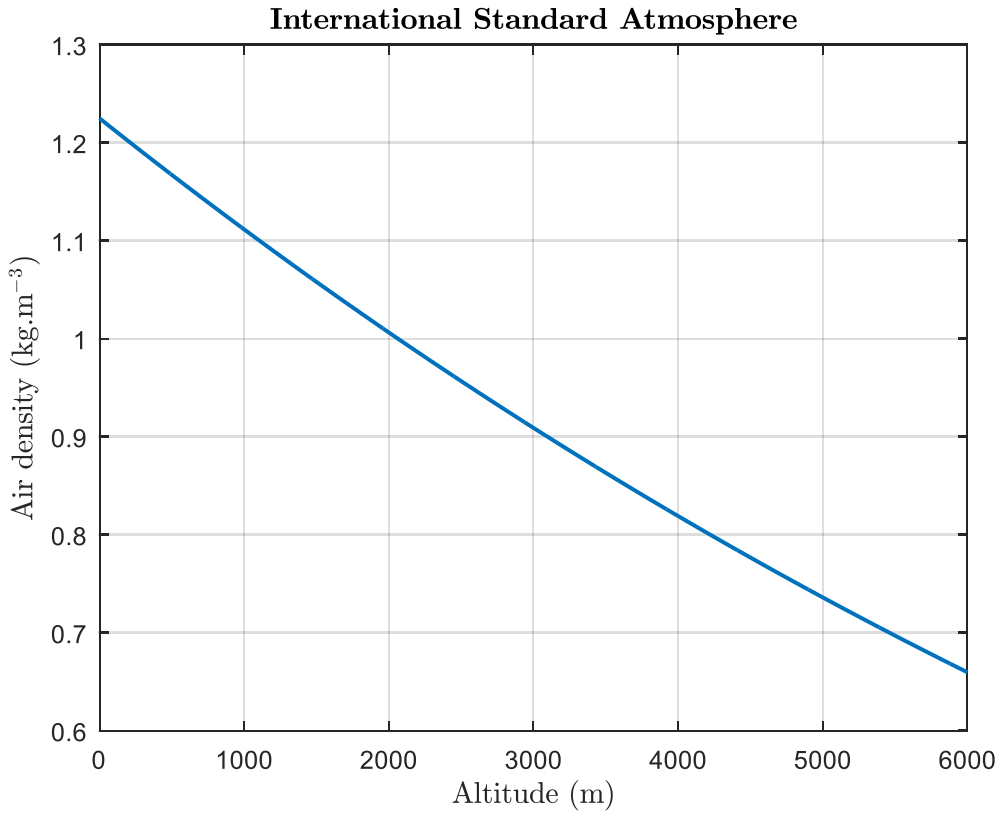
➡ **Inertial acceleration and angular velocity**

Quadrotor sensors

Barometer

Local static air pressure

Altitude

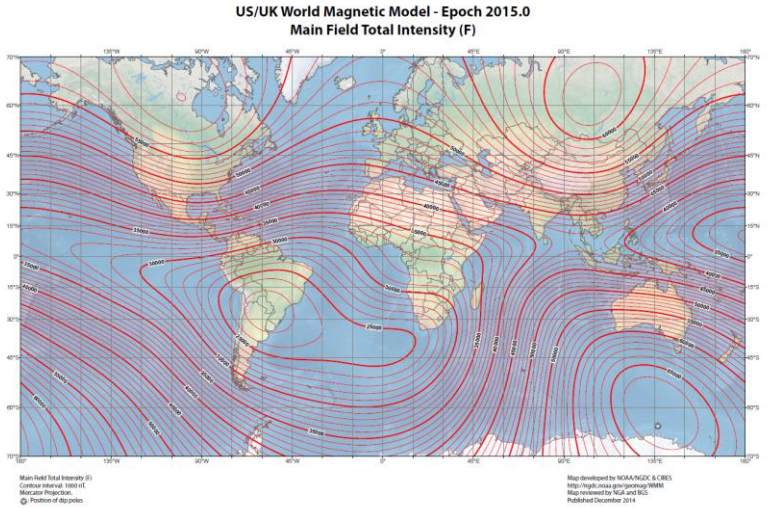


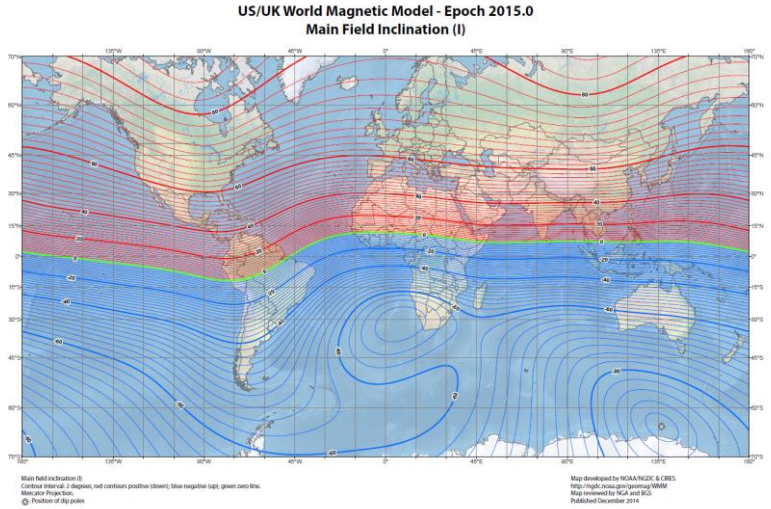
Quadrotor sensors

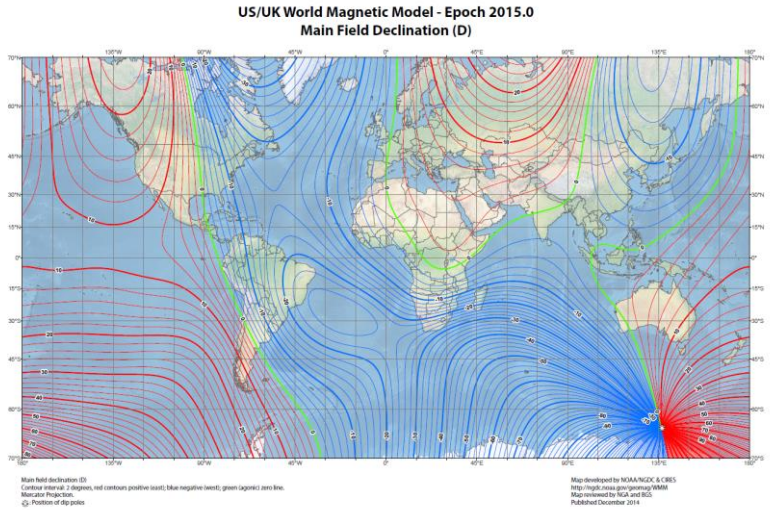
Magnetometer

Local 3D magnetic field

Heading





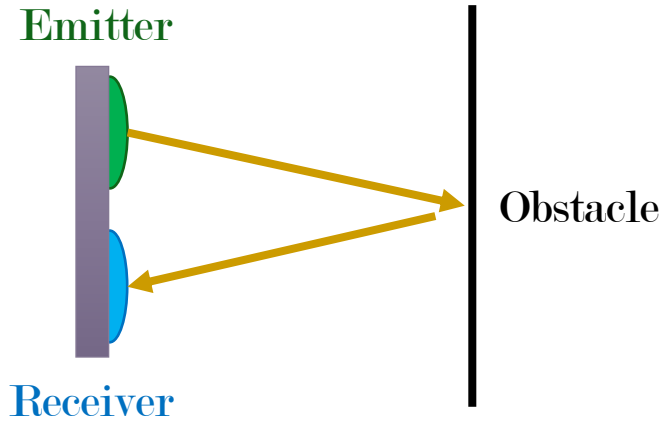


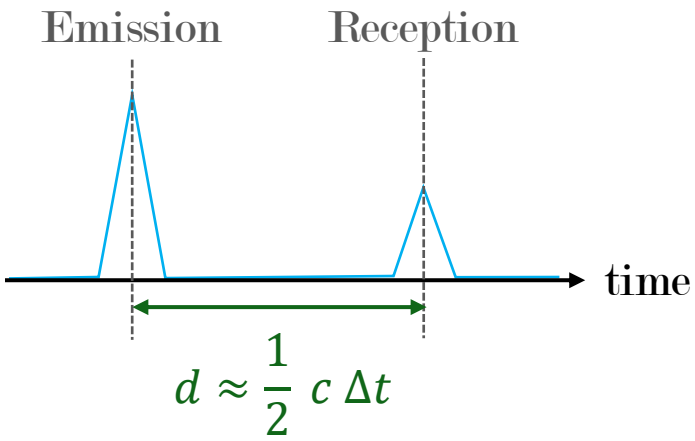
Quadrotor sensors

Time of Flight based sensors

Ultrasound (sonar)

Light (ToF IR, LIDAR, RADAR, …)





- **Ground altitude**
- **Sometimes: surrounding environment**

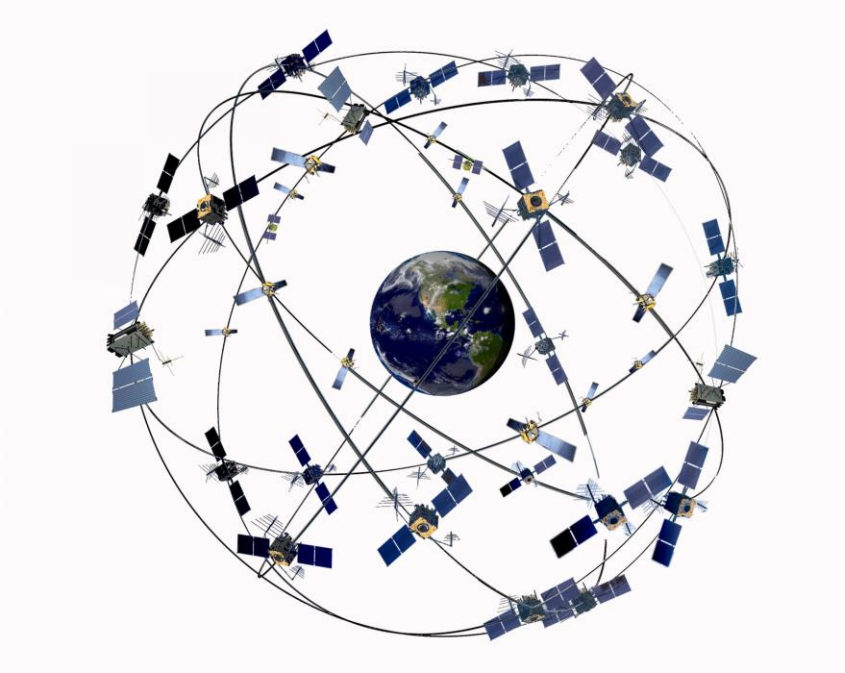
Quadrotor sensors

Global Navigation Satellite System (GNSS)

GPS, Galileo, GLONASS etc.

Ground stations

RTK

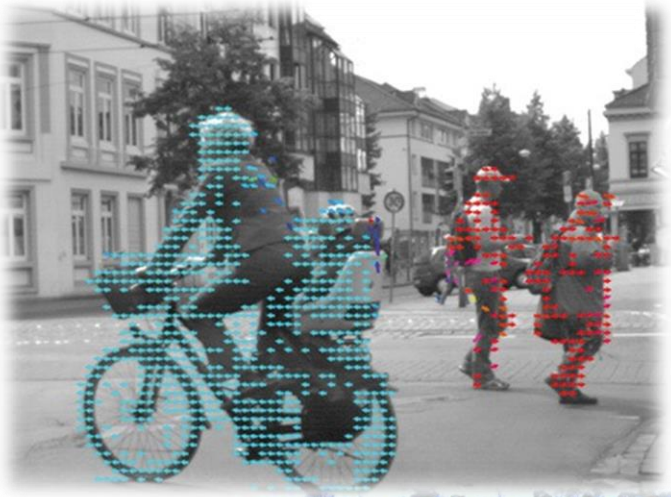


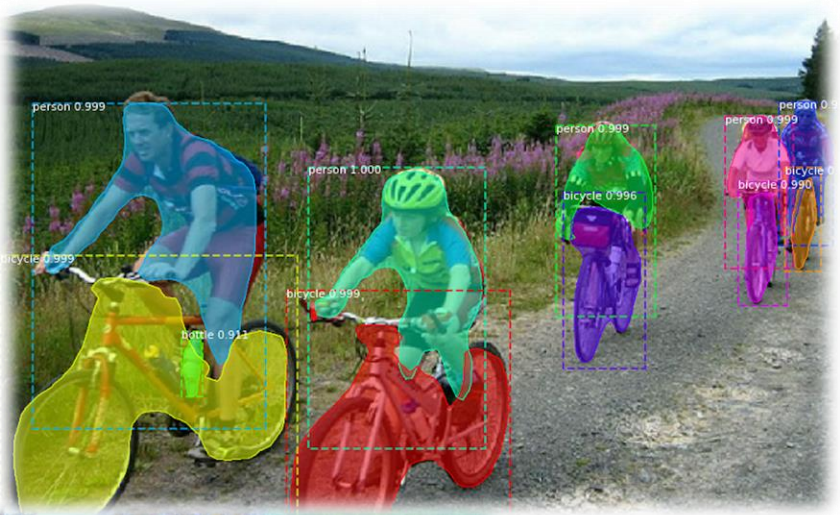
Geographic position and velocity

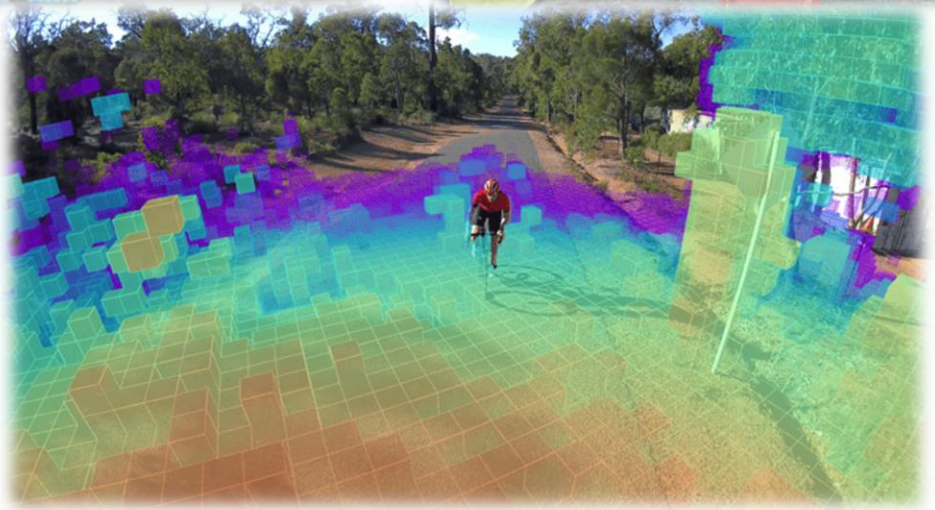
Precise relative position (RTK)

Quadrotor sensors

Cameras and computer vision







Optical flow

Stereo vision

Etc.

➡ **Motion relatively to environment**

➡ **Environment description**