Miniature autopilot for an outdoor flying robot

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Navigare 2012 - Adrien Briod

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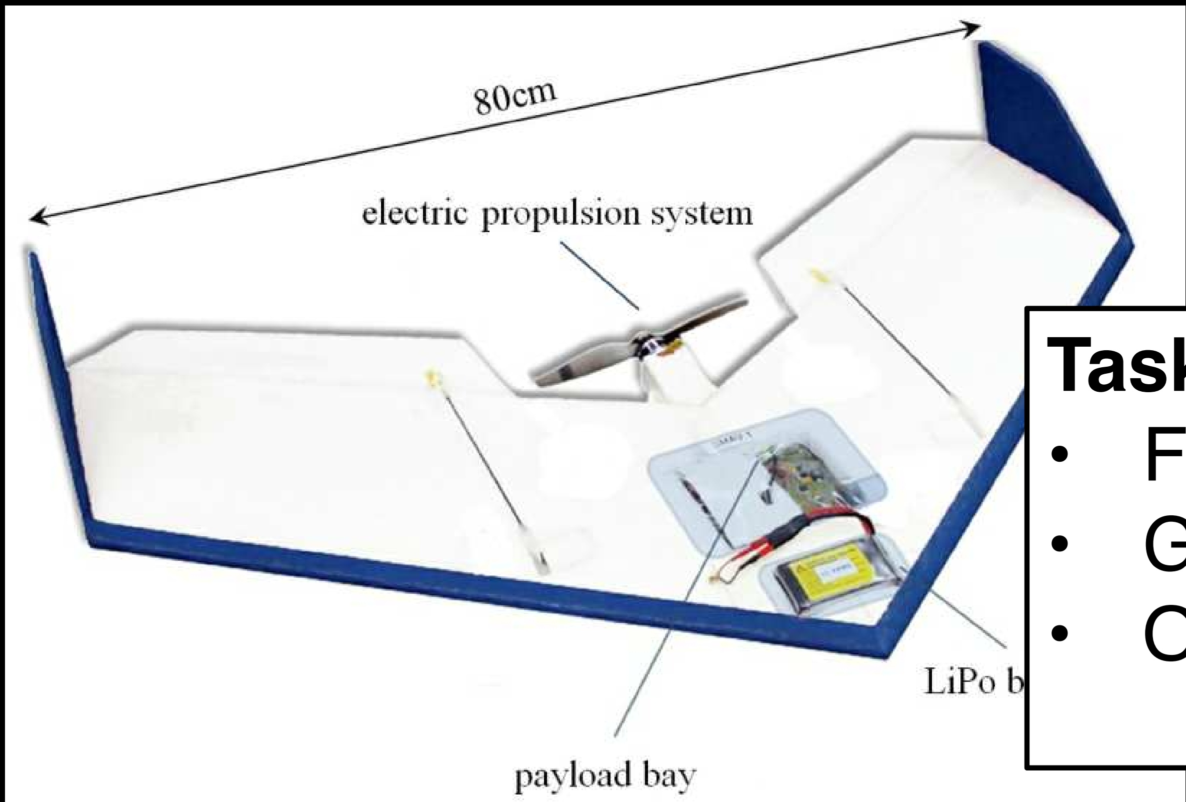
LIS

Goal

- Autonomous control of an outdoor flying robot:



80cm wingspan
400g
30min endurance

Tasks

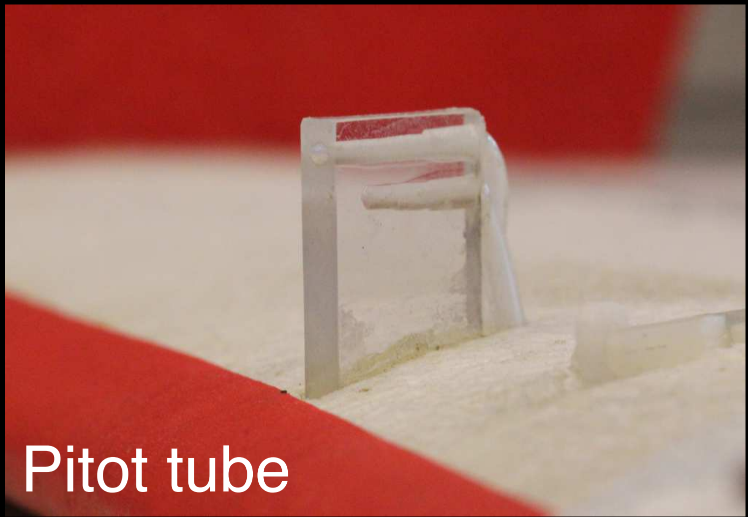
- Flight stabilization
- GPS navigation*
- Obstacle avoidance

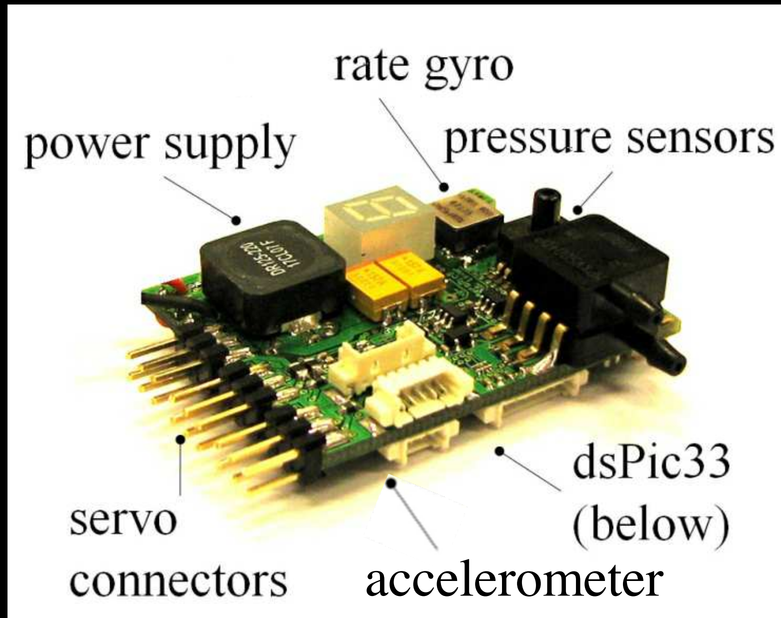
Flight stabilization

Orientation and speed control

Sensors for flight stabilization

- Autopilot sensors:
  - » 3 rate gyroscopes (ADXRS610)
  - » 3-axis accelerometer (MMA7260)
  - » Pressure sensors (static: MPXHZ6115A, dynamic: MPXV5004G)



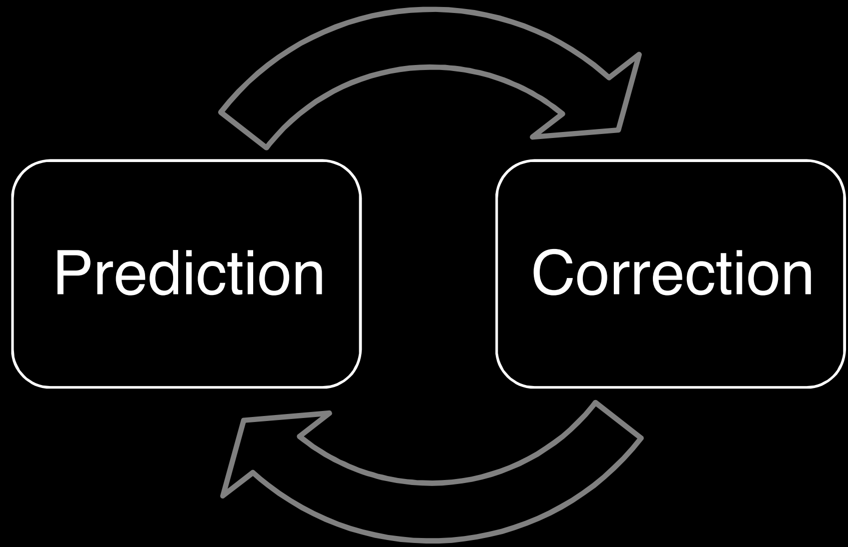


Orientation sensing

- Rate gyroscope and accelerometer sensor fusion
- Quaternion-based 7-states Kalman filter with gyroscope biases estimation
- Running on microcontroller

State: $$\mathbf{x} = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \\ \delta_x \\ \delta_y \\ \delta_z \end{bmatrix}$$

q: quaternions
δ: biases



Orientation sensing (2)

Prediction:

$$\dot{q} = \frac{1}{2} Q \cdot q$$

$$Q = \begin{bmatrix} 0 & -w_x & -w_y & -w_z \\ w_x & 0 & w_z & -w_y \\ w_y & -w_z & 0 & w_x \\ w_z & w_y & -w_x & 0 \end{bmatrix}$$

ω: angular speed

Correction:

Measurement: $\mathbf{z} = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}$

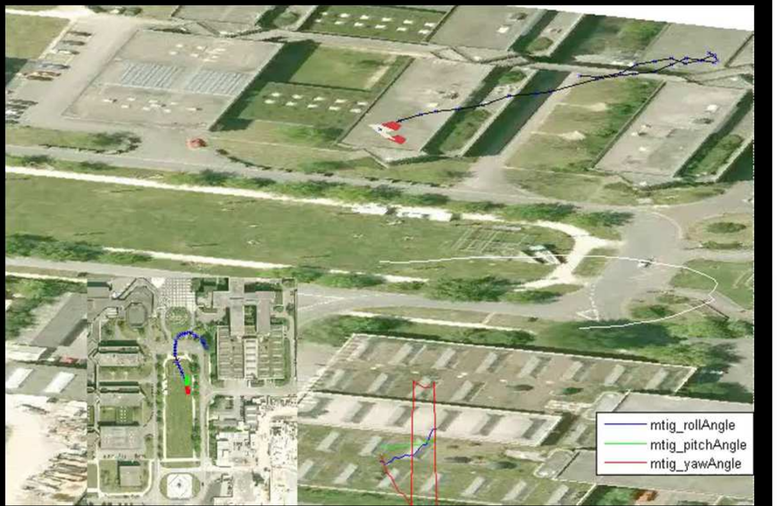
Model: $h = R^{-1} \cdot \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} + \boldsymbol{\omega} \times \mathbf{v}$

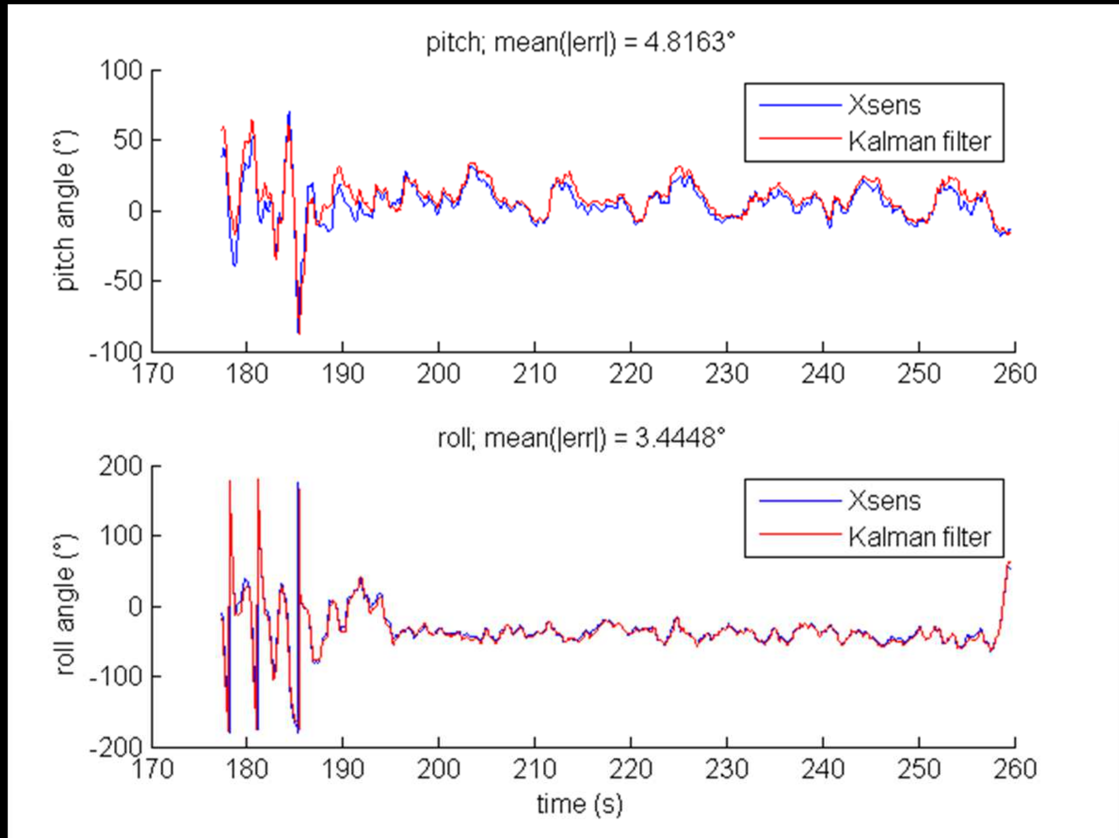
a: acceleration
g: gravity
v: velocity
R: rotation matrix

- Centrifugal acceleration compensation

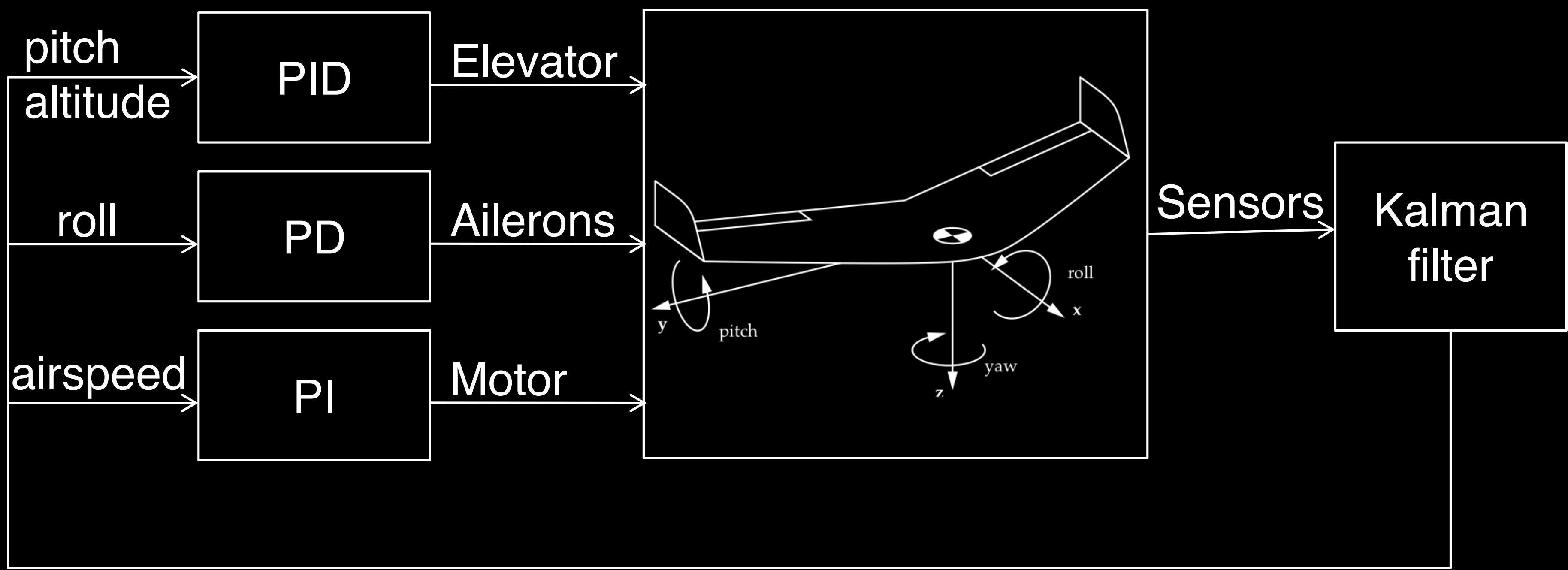
Orientation sensing - Results

- Output: roll & pitch





Flight stabilization

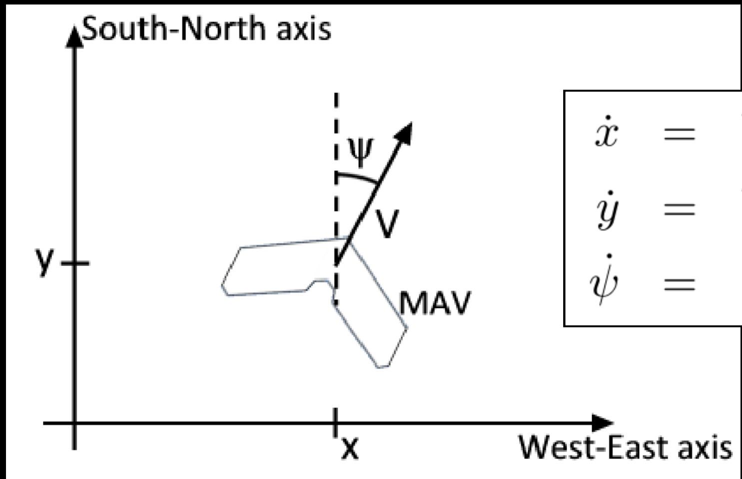


GPS navigation

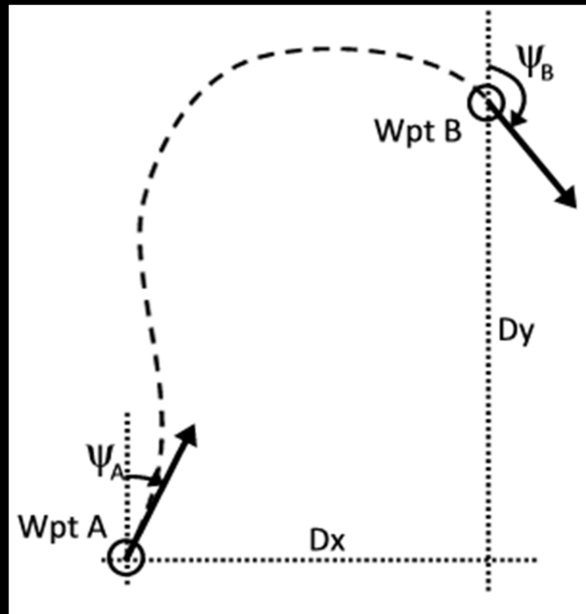
Position control

Description of the problem

- GPS Sensor: U-blox Antaris LEA-4H
- Task: Control the robot from waypoint A to waypoint B
- Challenge: Nonholonomic system
  - » Control input: $\dot{\Psi}_c$ *(turn rate)*



$$
\begin{aligned}
\dot{x} &= V \cdot \sin \Psi \\
\dot{y} &= V \cdot \cos \Psi \\
\dot{\psi} &= \dot{\Psi}_c
\end{aligned}
$$

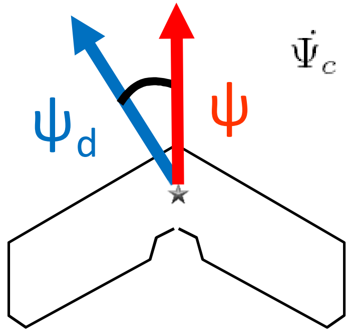


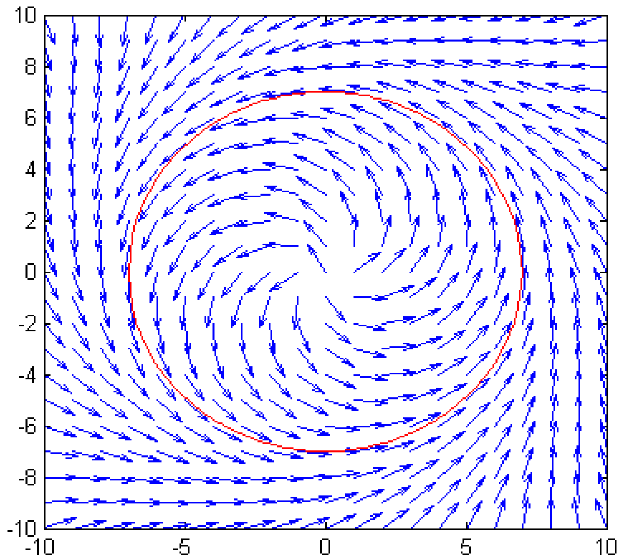
Following lines and circles

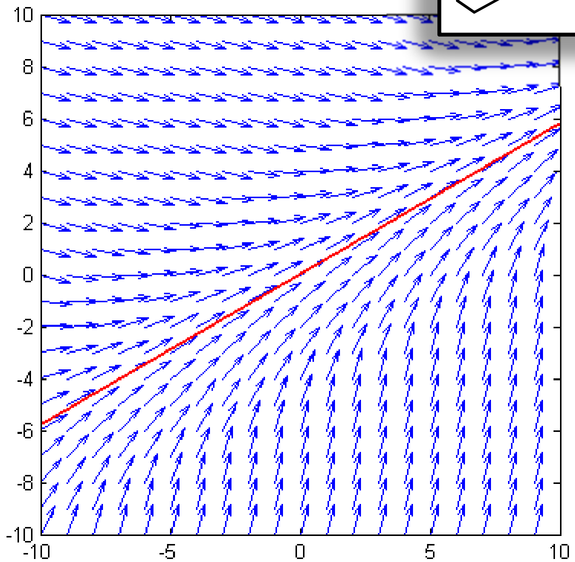
- Vector fields
- Control GPS Heading

A priori + proportional control :

$$\dot{\Psi}_c = \dot{\Psi}_d + K \cdot (\Psi_d - \Psi)$$





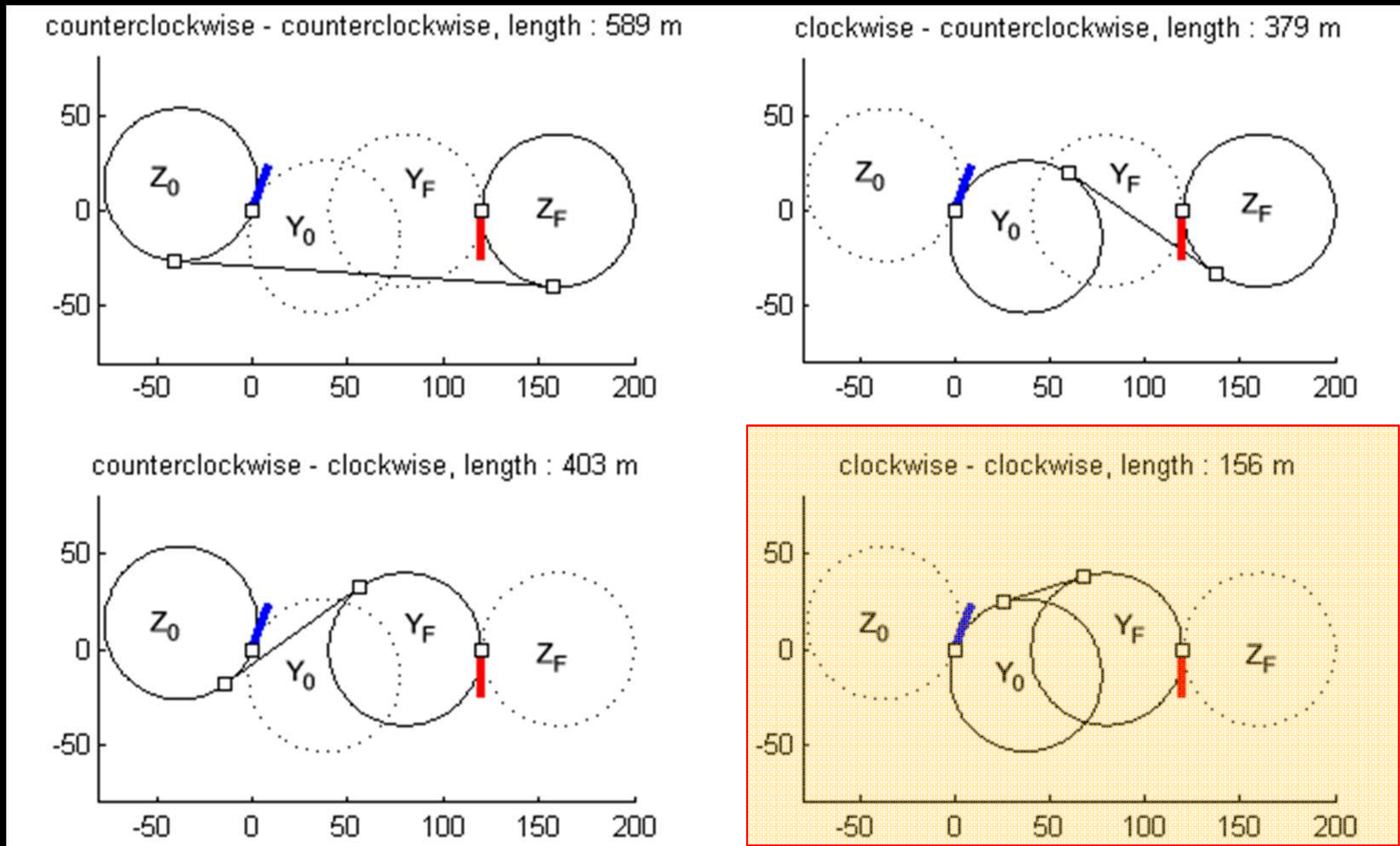


Ψ: GPS heading

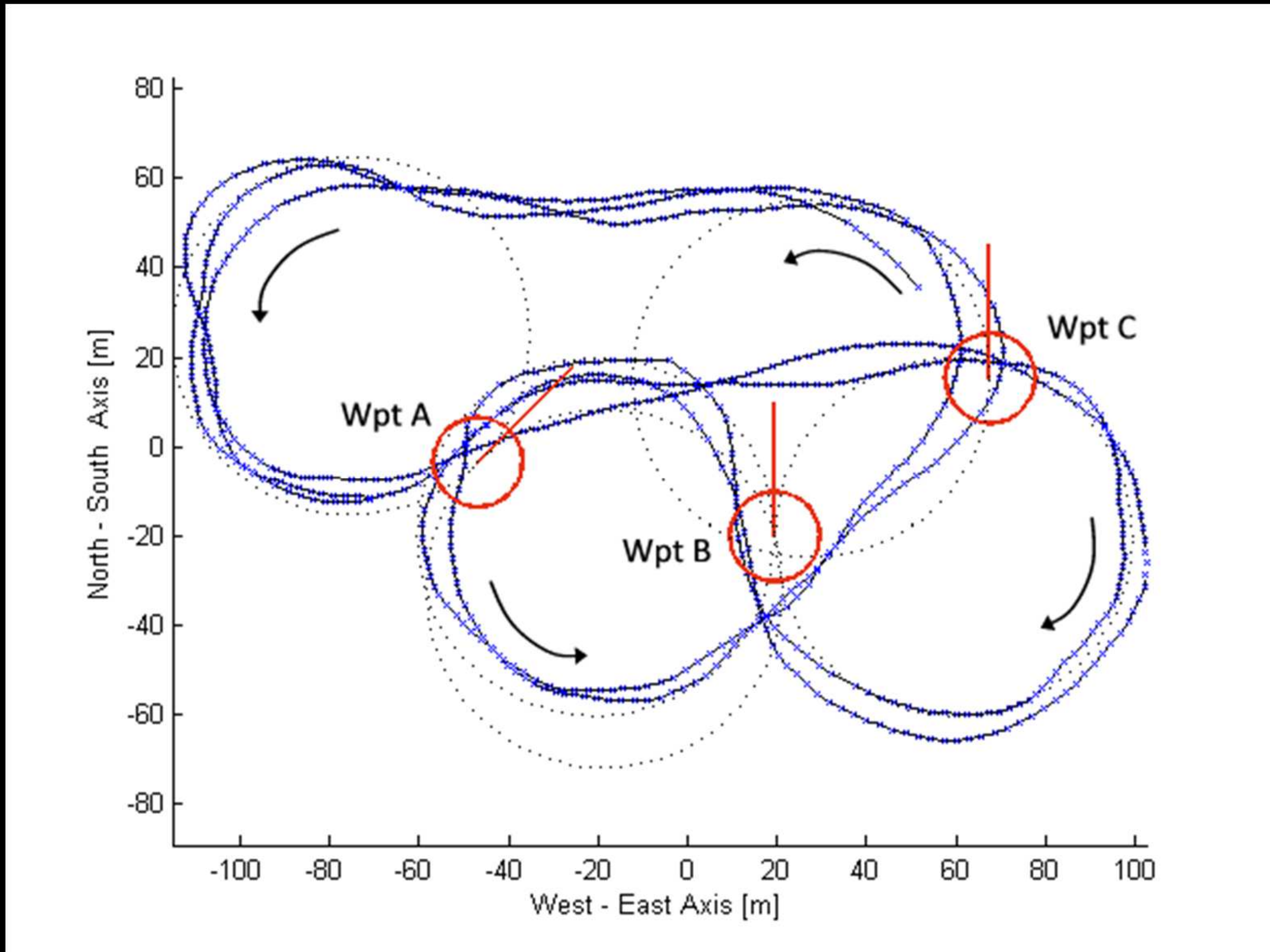
Ψ_d: desired heading

Dubin's trajectories

- Generate arc-line-arc trajectories that fit the plane's dynamics



GPS Navigation - Results

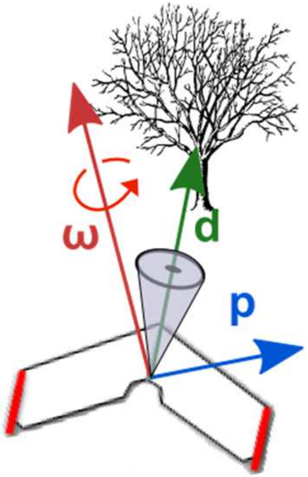


Obstacle avoidance

Optic-flow sensors

- Task: Detect obstacles and navigate around them
- Sensors used: ADNS-5050 optic-flow sensors
  - Measures the displacement speed (**p**) of the image

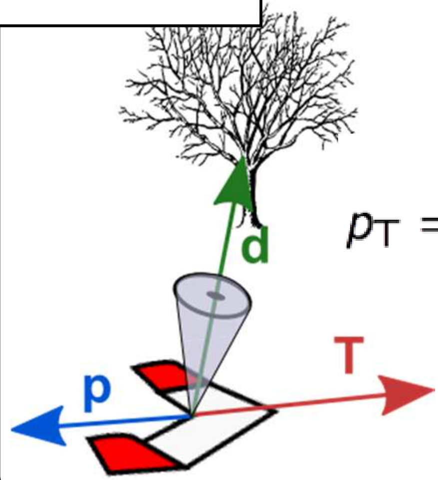
Rotation ω:



$$\mathbf{p}_R = -\boldsymbol{\omega} \times \mathbf{d}$$

d: unitary direction vector

Translation T:

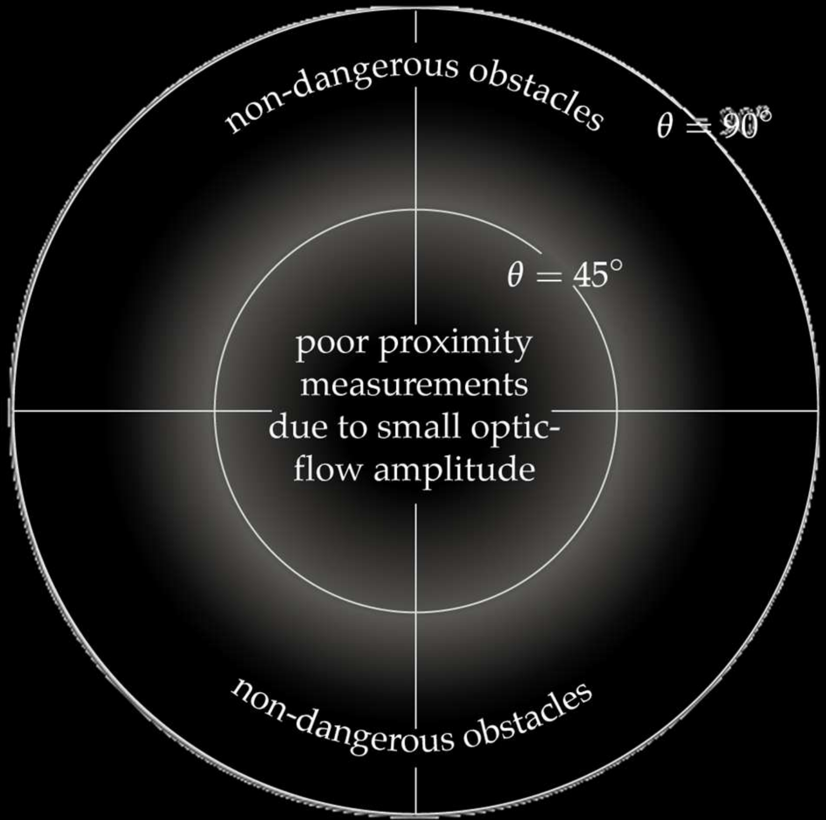


$$p_T = \frac{|\mathbf{T}|}{D} \cdot \sin\angle(\mathbf{T}, \mathbf{d})$$

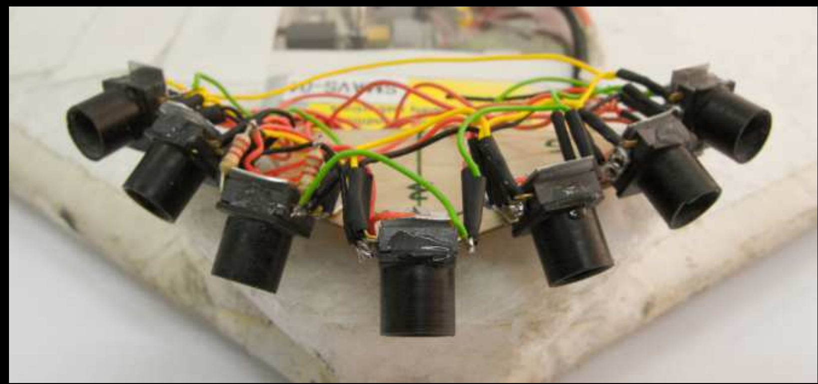
D: distance to obstacle

Sensor configuration

- Simulations led to an optimal sensor configuration for obstacle avoidance

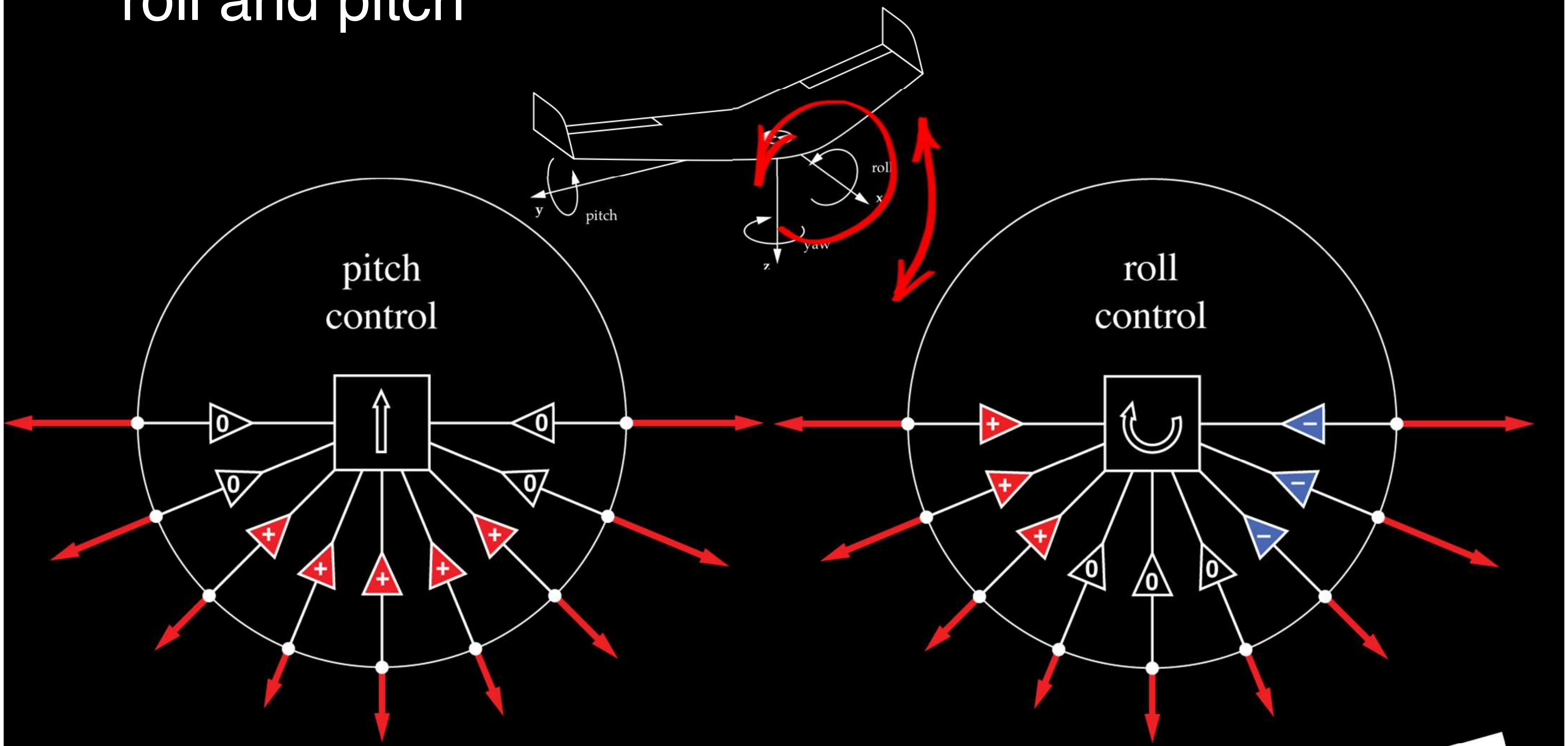


Optipilot front-end:



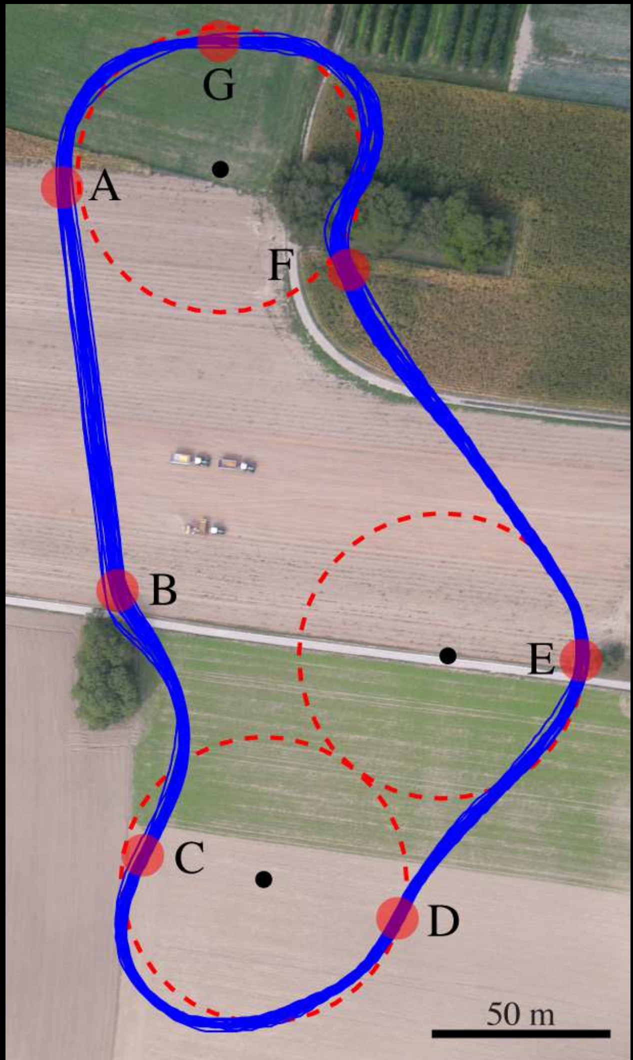
Control

- Optic-flow measurements are weighted to control roll and pitch



Obstacle avoidance - Results

Final demo



- 2 low-altitude flights of 25 minutes
- 32km in 46 laps
- 90 potential collisions avoided

Questions ?

Acknowledgments:
Dario Floreano,
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Severin Leven,
Antoine Beyeler

http://lis.epfl.ch

Aerial imagery

www.sensefly.com

Fully autonomous using GPS+IMU+Pitot

EPP foam => safe & crash resistant

Max 500 g including 150 g payload

Cross-platform & open source software