THE NAVIGATION AND CONTROL TECHNOLOGY INSIDE THE AR.DRONE MICRO UAV

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Nicolas Petit*

* Centre Automatique et Systèmes
MINES ParisTech

**Parrot

***SYSNAV

May 26th 2011
GT-UAV

INTRODUCTION

- Collaboration
- Mass-market : robustness and high stability
- Mass-market : low-cost and user-friendly

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Parrot move wireless SYSNAV Navigation Solutions MINES ParisTech

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OUTLINE

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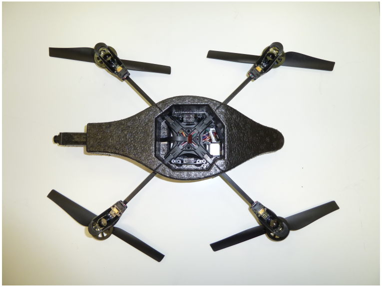
QUADROTOR

- carbon fiber frame, highly resistant plastic structure
- four brushless motors with microcontroller and cutout system, 3500 rpm
- one battery LiPo 11.1 V, 1000 mAh, 80g
- two electronic boards
- two different hulls (expanded polypropylene)



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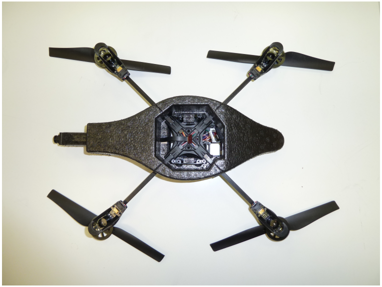

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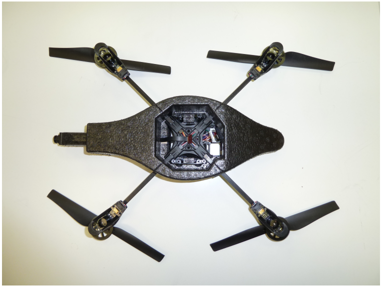

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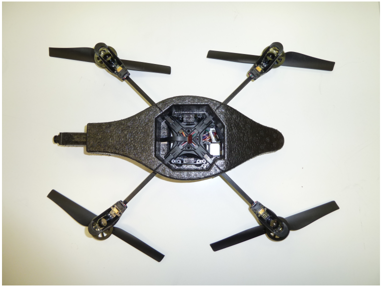

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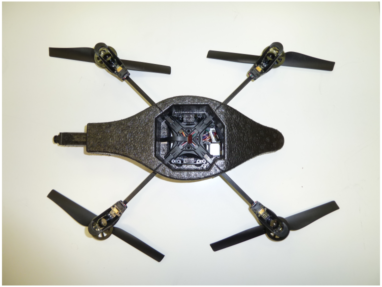

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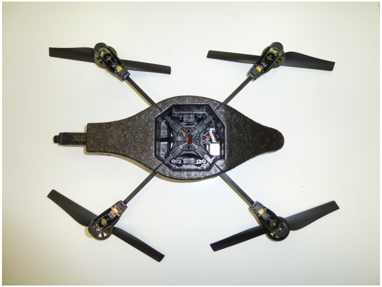

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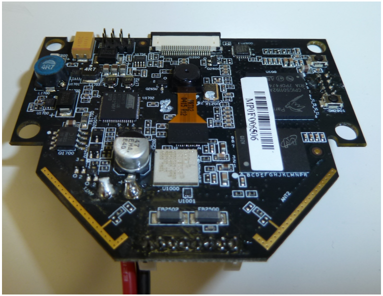
- Parrot P6 processor, 468 MHz
- WiFi chip (ad hoc network)
- vertical camera, 60 fps
- Linux based real-time operating system, control thread at 200 Hz



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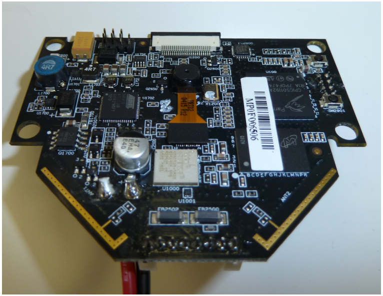

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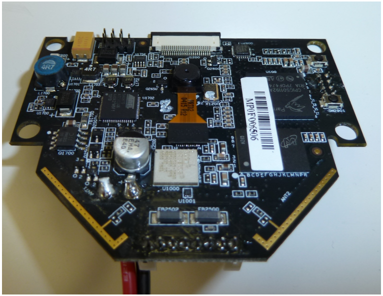

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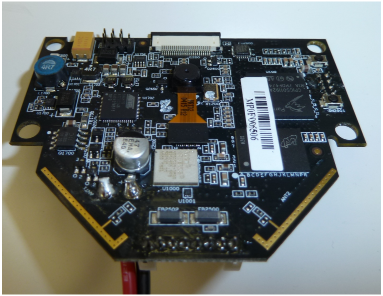

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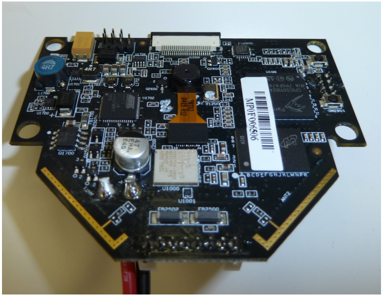
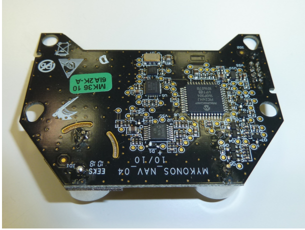


Navigation board

Inertial Measurement Unit

- 3-axis accelerometer, Bosch BMA150, FS $\pm$ 2g
- 2-axis gyrometer, Invensense IDG500, FS $\pm$ 500°/s
- 1-axis gyrometer, Epson XV3700, FS $\pm$ 1500°/s
- Data acquisition at 200 Hz
- $\approx$ 10 USD

- 2 Prowave ultrasonic sensors, FS 6m, 25 Hz



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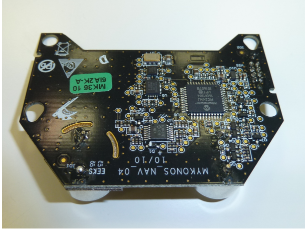

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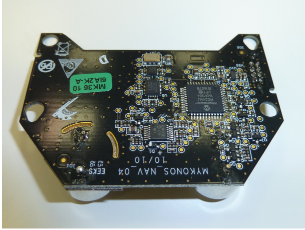

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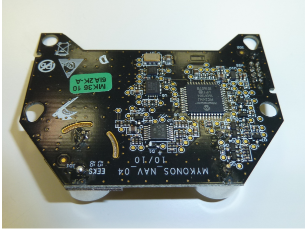

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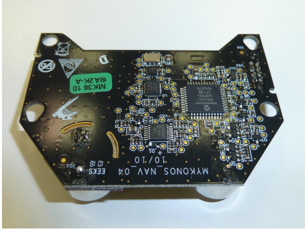

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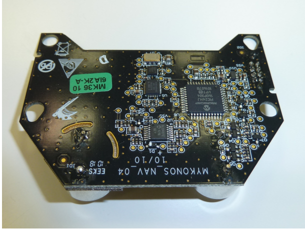

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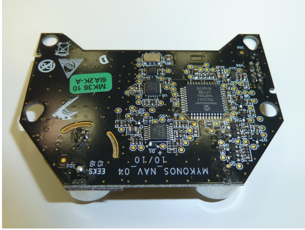

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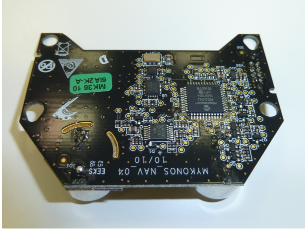

OUTLINE

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FACTORY CALIBRATION

- Accelerometer calibration : least-squares optimization for misalignments, scale factors, offsets

$$Y_m = AY_r + B$$

- Gyrometer calibration : least-squares optimization for misalignments, scale factors, offsets

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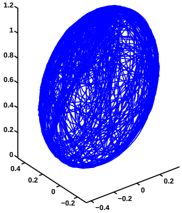

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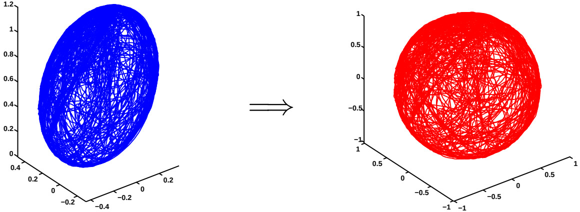

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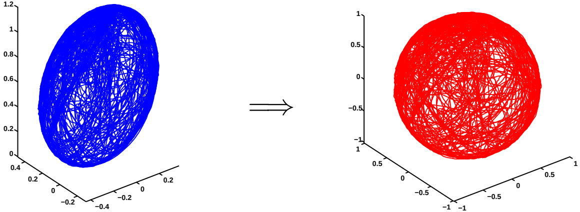

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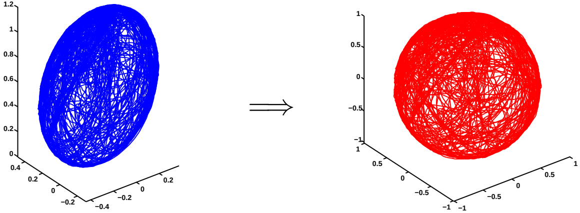

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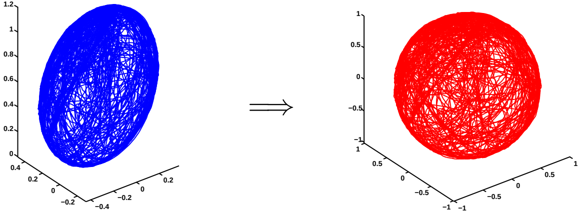

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- IMU calibrated at factory but not precisely aligned with the aerial platform
- Determination of micro-rotation such that mean specific acceleration is zero during hovering
- Only roll and pitch corrections
- Execution after each take-off due to possible displacement during landing shock

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Attitude estimation

- Accelerometer noisy but considered debiased

$$Y_V = F - R\vec{g} + \mu_V$$

- Gyrometer noisy and biased

- Observer based on complementary filter
  Orientation given by low-pass filter on accelerometer
  Angular rates given by high-pass filter on gyrometer

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Images correction

- Objective of video processing : horizontal velocity
- Image compensation for angular rates
- Micro-rotations matrix from the debiased gyrometers

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$$\delta R = \begin{bmatrix} 1 & r\delta t & -q\delta t \\ -r\delta t & 1 & p\delta t \\ q\delta t & -p\delta t & 1 \end{bmatrix}$$

VIDEO PROCESSING

- Two complementary algorithms
- Compensation of vertical dynamics thanks to altitude observer from ultrasonic sensors
- Optical flow technique
  - High speed
    Very low contrast scenes
- Corner tracking
  - Low speed
    Ground highly textured
- Automatic switch based on speed value and trackers number

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AERODYNAMICS MODELING

- Transposition of large-size rotors modeling techniques
- Consideration of the velocities and the angular rates of the vehicle
- Blade element theory
- Consideration of the rotor in the moving body frame

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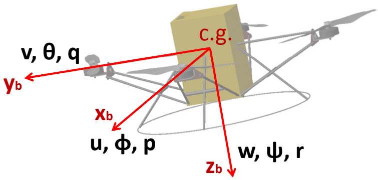

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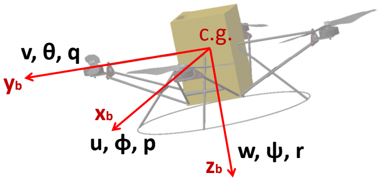

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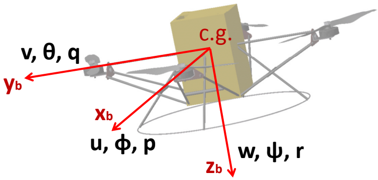

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- Linear and stabilizing aerodynamic effect
- Introduction of blades flexibility
- Modifications of the lift effects mainly
- Stabilized flapping angles proportional to speed

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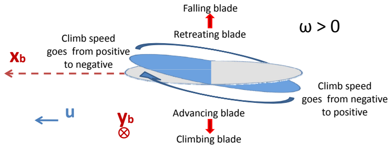

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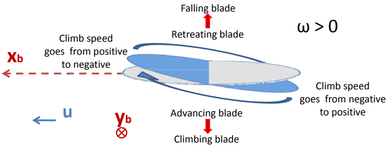

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$$\mathbf{LF} = \rho c R^3 \omega^2 C_{L\alpha}\left(\frac{\alpha_t}{3} - \frac{L}{2R|\omega|}(\varepsilon_1 q - \varepsilon_2 p)\right)\begin{bmatrix}-a\\-b\\1\end{bmatrix}$$

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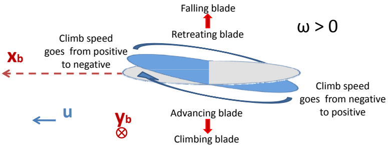

- Modifications of the lift effects mainly

$$\mathbf{LF} = \rho c R^3 \omega^2 C_{L\alpha}\left(\frac{\alpha_t}{3} - \frac{L}{2R|\omega|}(\varepsilon_1 q - \varepsilon_2 p)\right)\begin{bmatrix}-a\\-b\\1\end{bmatrix}$$

- Stabilized flapping angles proportional to speed

AERODYNAMICS MODEL EXPLOITATION

- Existence of a linear term in the drag force induced by the rotors
- Reinforcement of this term by the blades flexibility
- Observer based on complementary filter

Aerodynamics model exploitation

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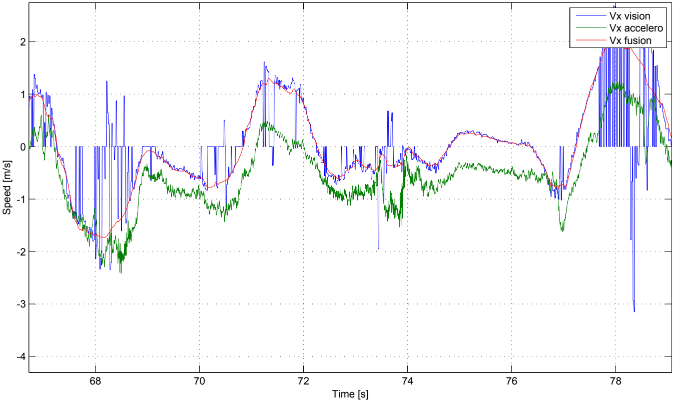
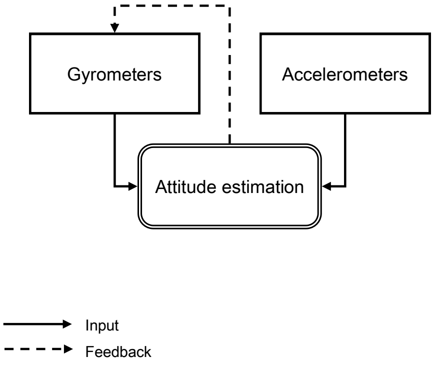


Navigation scheme



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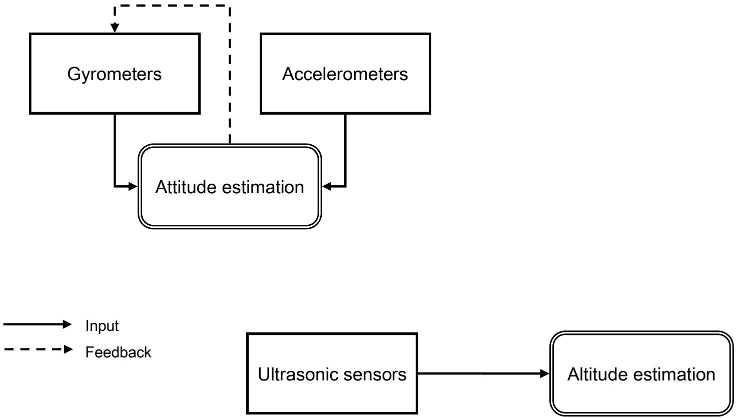
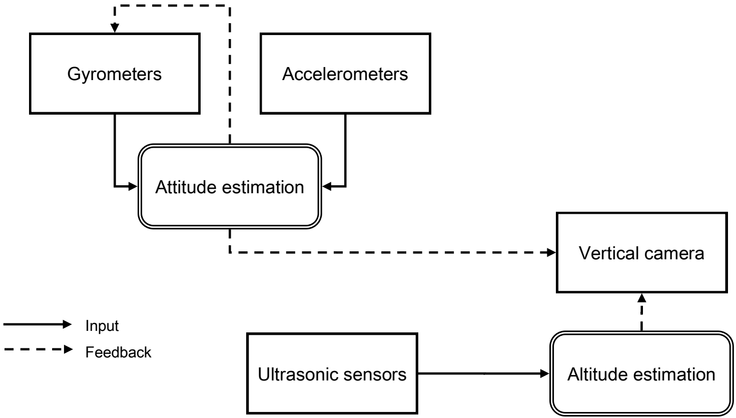


NAVIGATION SCHEME



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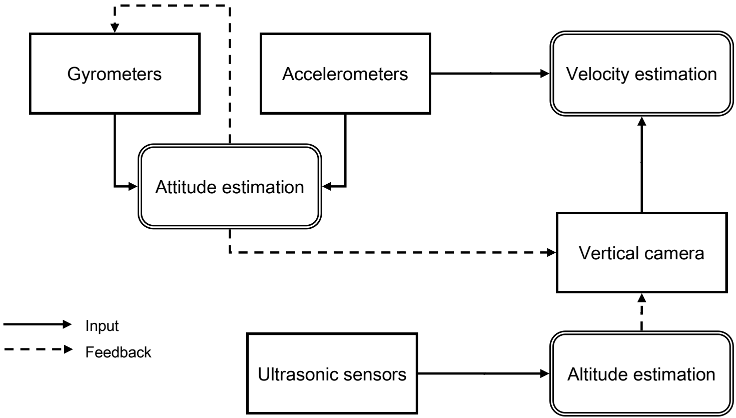

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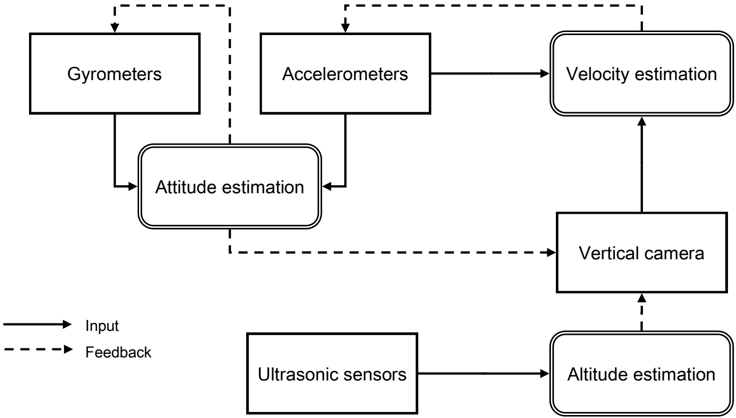

Heading estimation

- Use of magnetometers
- Problem : perturbations created by the quadrotor, static and dynamic
- Factory calibration to eliminate intrinsic distortion
- Off-line modeling of motor magnetic field function of rotation speed
- Onboard identification of static perturbations : soft iron, hard iron
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OUTLINE

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- Roll and pitch angles directly controlled by controller inclination
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- Two nested loops
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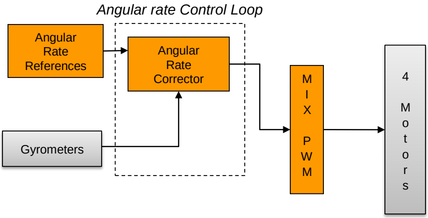

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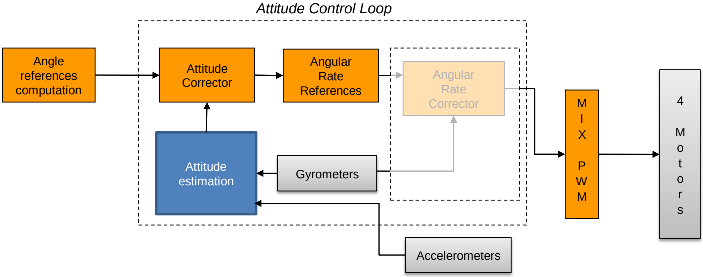

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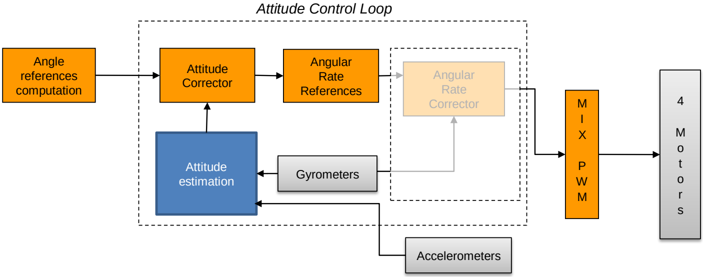

ATTITUDE SETPOINT COMPUTATION

- In flight mode, setpoint defined by the user
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$$u = -g\theta - C_x u$$

  - Look-up table from close-loop identification of attitude dynamics depending of the initial speed

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Initial speed	Outdoor hull	Indoor hull
$u_0 < 3$ m.s^{-1}	0.7 s	1.5 s
$3 < u_0 < 6$ m.s^{-1}	1.0 s	2.2 s
$u_0 > 6$ m.s^{-1}	1.5 s	2.4 s

TABLE: Stop times for different initial speed

HOVERING CONTROL LOOP

- Zero attitude setpoint
- Zero speed setpoint
- PI controller on speed estimate to compute attitude reference

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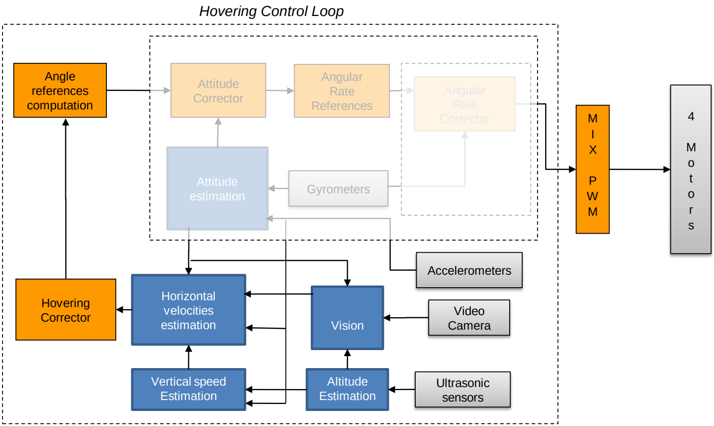
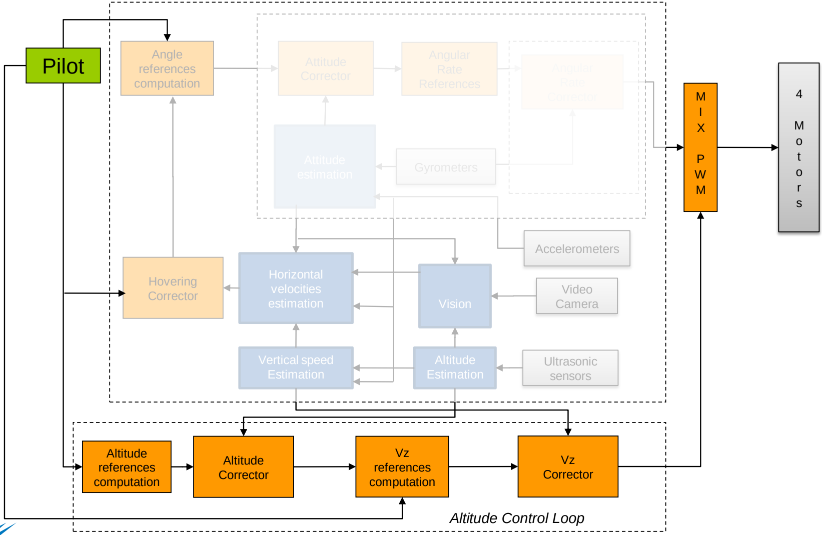


PILOT CONTROL



OUTLINE

CONCLUSIONS

- Quadrotor very popular in academic world
- Estimation problem solved without external sensors
  - Complex combination of inertial sensors and vision
  - Exploitation of the different sensors time-horizons
  - Importance of the aerodynamics model
- Development of low-level control algorithms to guarantee stability and user-friendliness
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