Electronic design and Automatic flight control

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Content

1. Electrical design
    a. Global electronics
    b. Power management board
2. Communications solution
3. Pixhawk controller
4. Model identification of the plane
    a. In-flight
    b. Off-flight
5. Simulation on the attitude controller
6. Further work in control

Electrical design

Main goal :

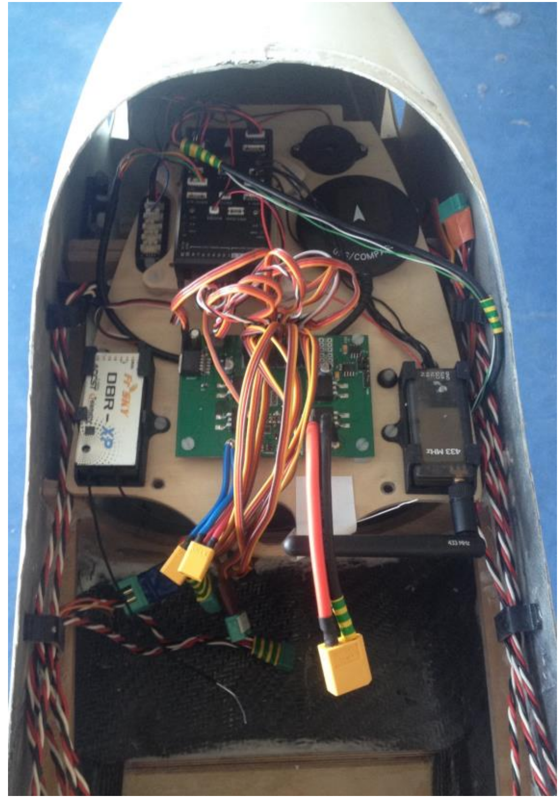
- Redundancy
- Reliability

Two power sources :

- 30 V Batteries / Fuel cell
- 8.4 V Emergency Battery (flight controller and servos)

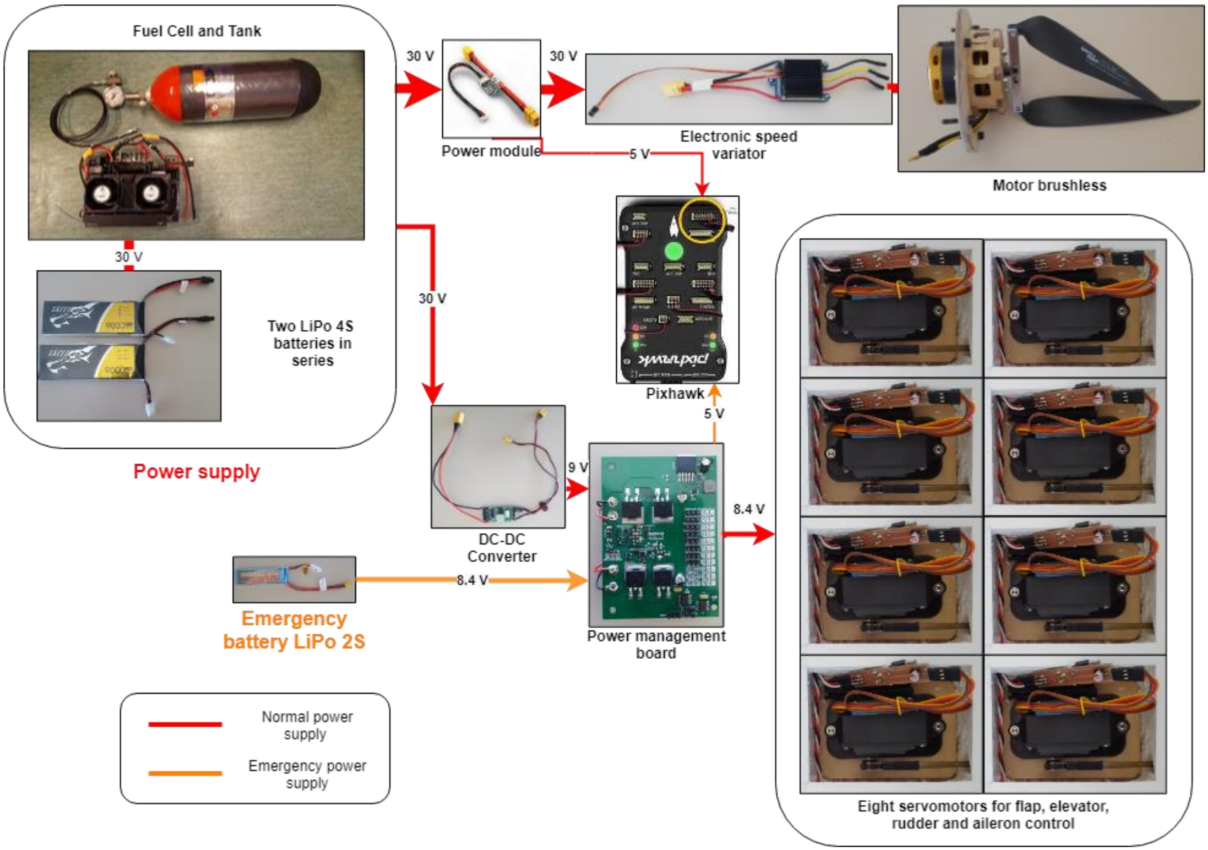
Flight controller :

- Pixhawk board
- PX4 Software



Embedded electronics

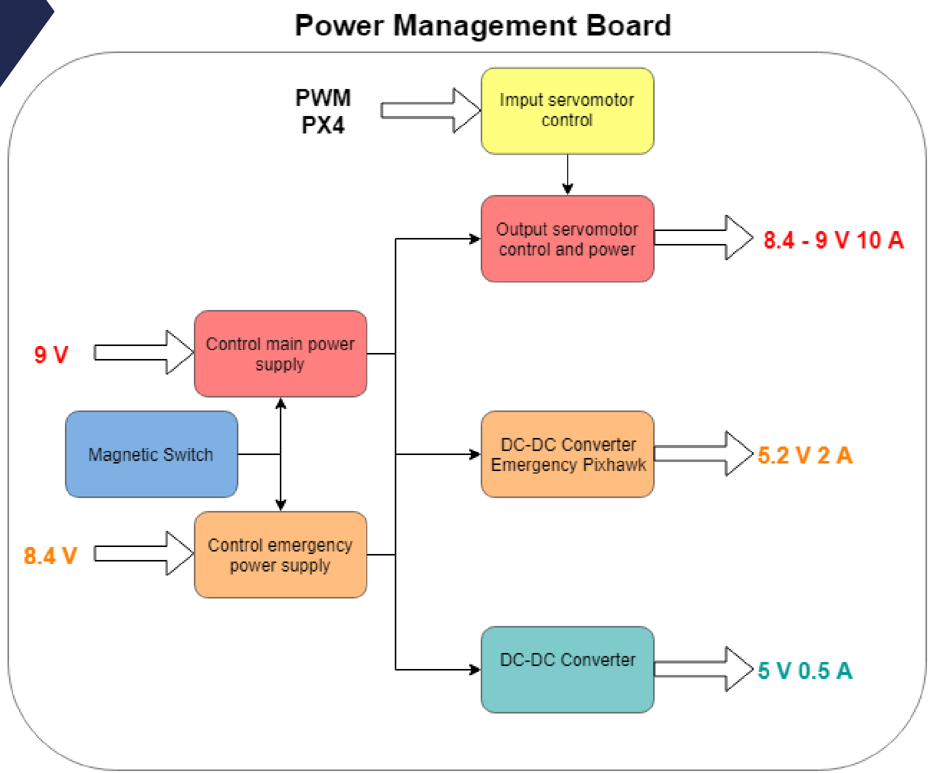
Electronic schematic on ELCOD Drone (Stork)



Power management board

Features :

- Management between normal and emergency supply
- Magnetic switch
- Ideal circuit diode
- 5V DC-DC
- Power supply for servomotors



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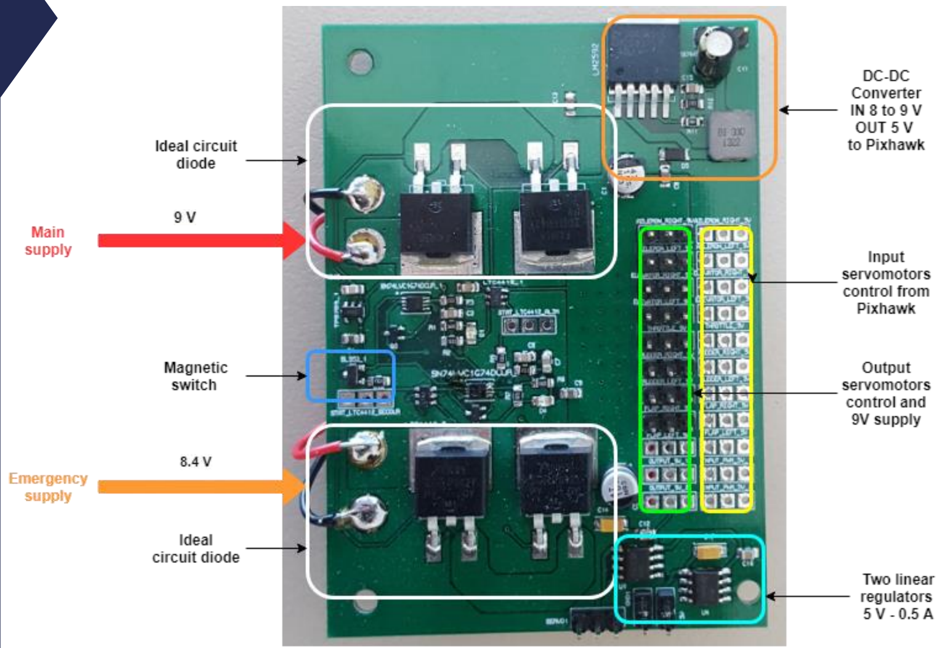


elcod sky solution

Communication solutions

Data link (Position, on board sensors, flight orders and flight mode)

- Short range (1 to 2 km) : Zigbee, Wifi or bluetooth
- Long range : GSM/GPRS mixed to an iridium Satellite

Manual remote control

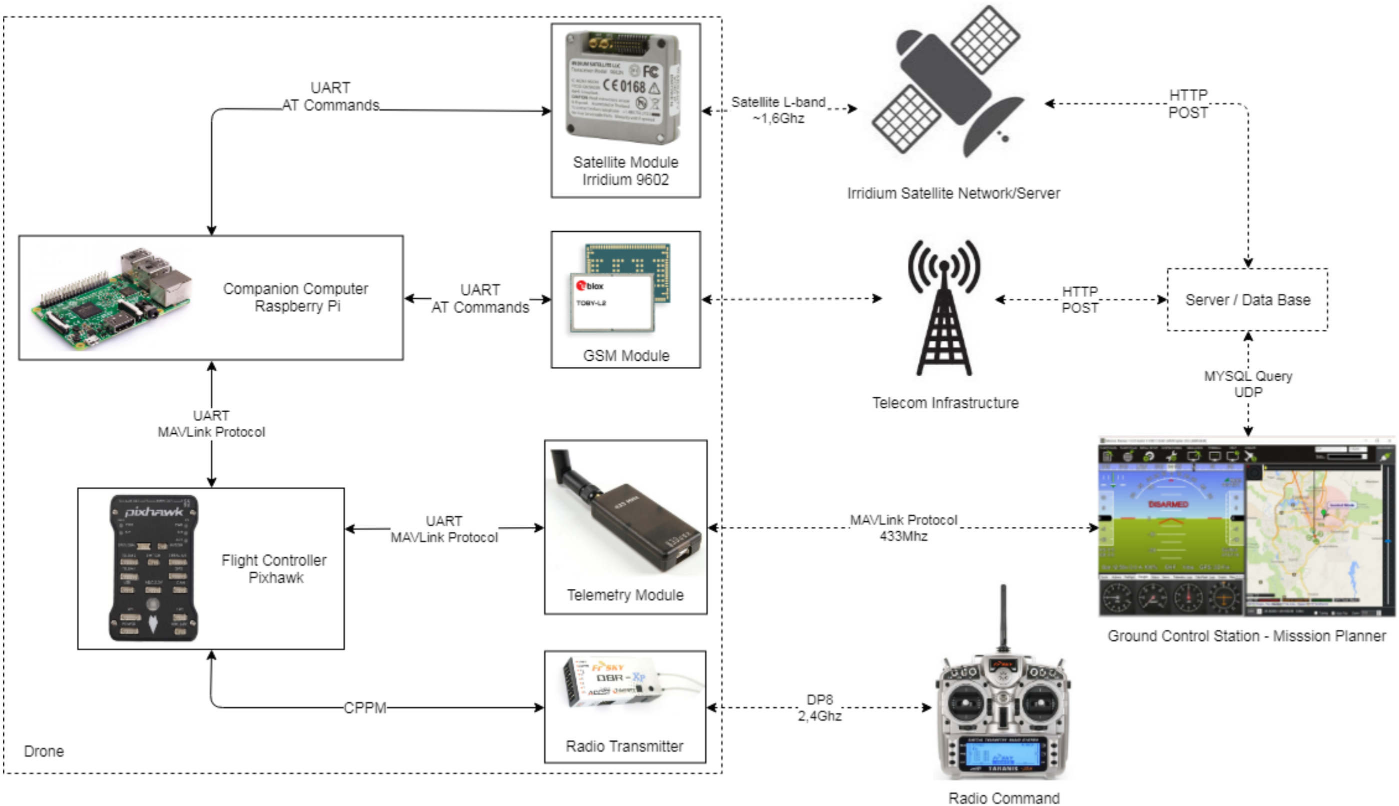
- Classical radio link in 2.4Ghz

ZigBee®

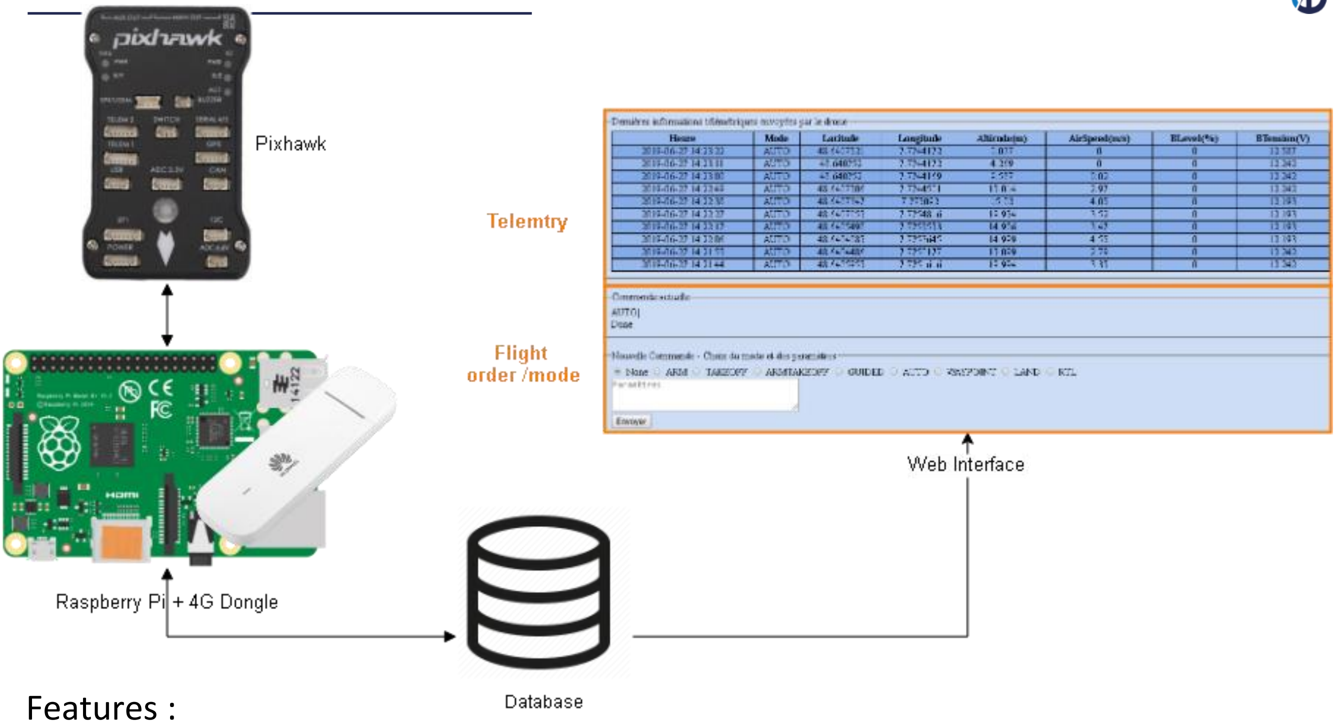
GSM®
GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS

iridium® Everywhere

Communication schematic



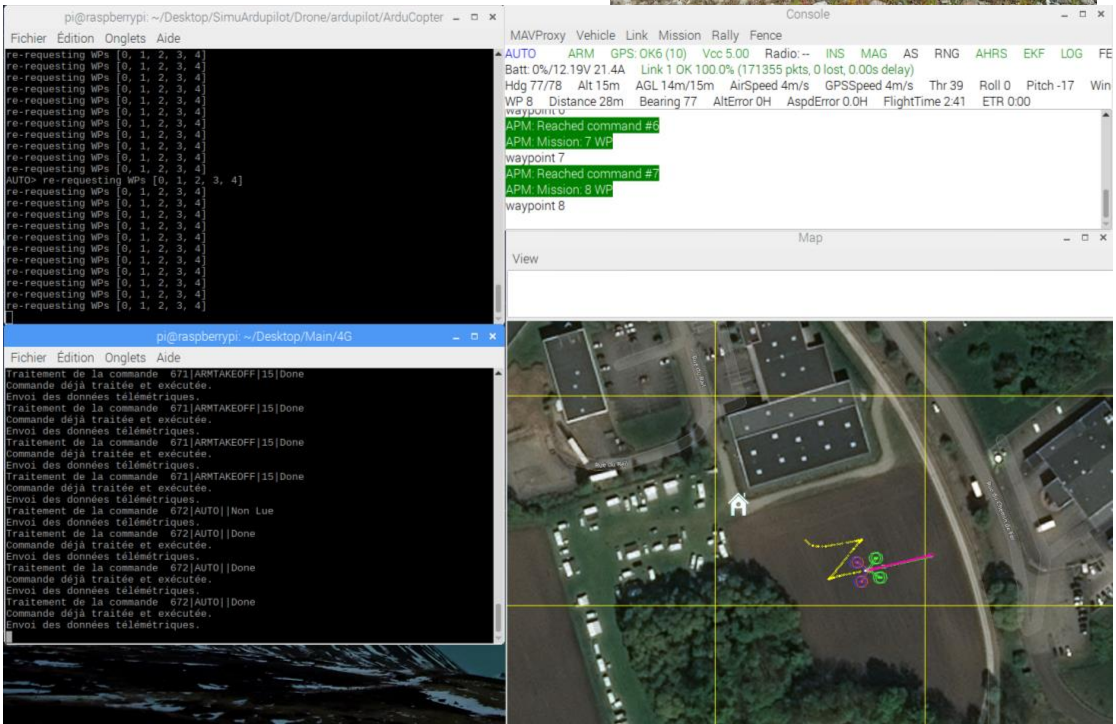
Bi-directional GSM Link



Features :

- Raspberry communicating Pixhawk through dronekit with a UART Link
- SQL database to manage data with a Web Interface
- 4g dongle to enable communication between the drone and the web

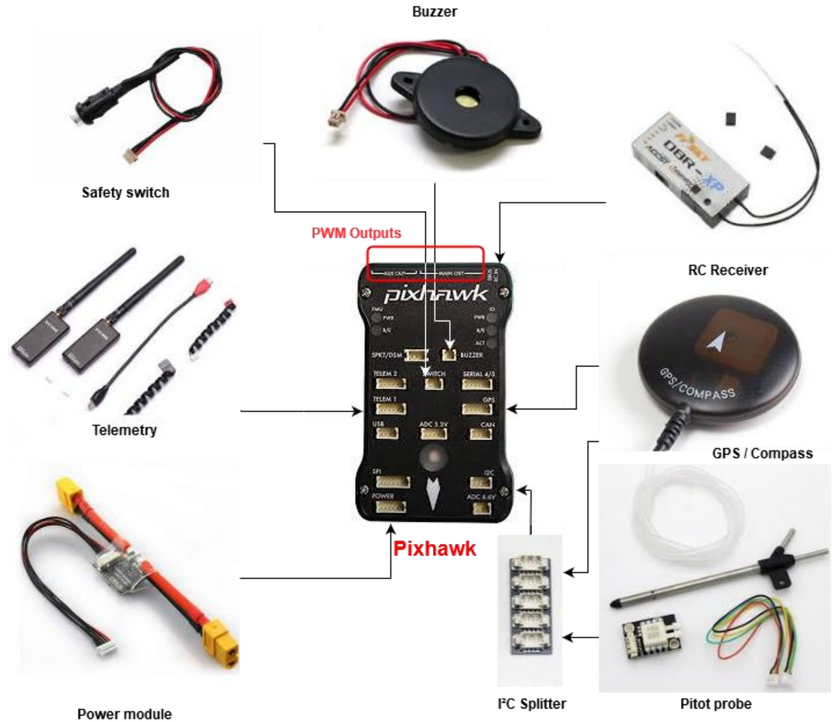
Simulation and testing



Software simulation by ardupilot simulator

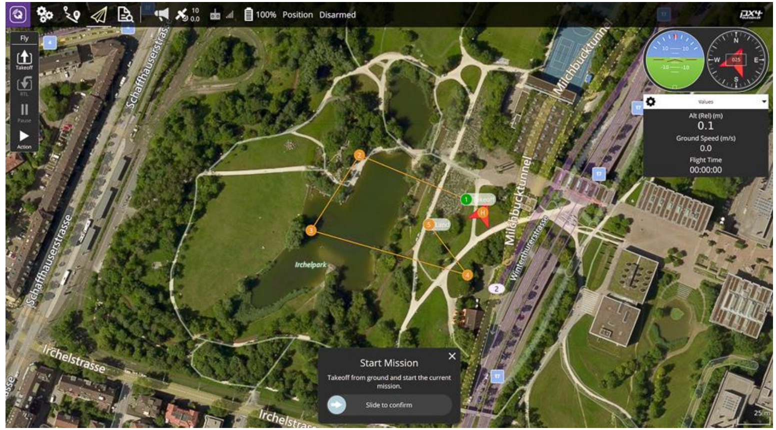
Flight controller : Pixhawk

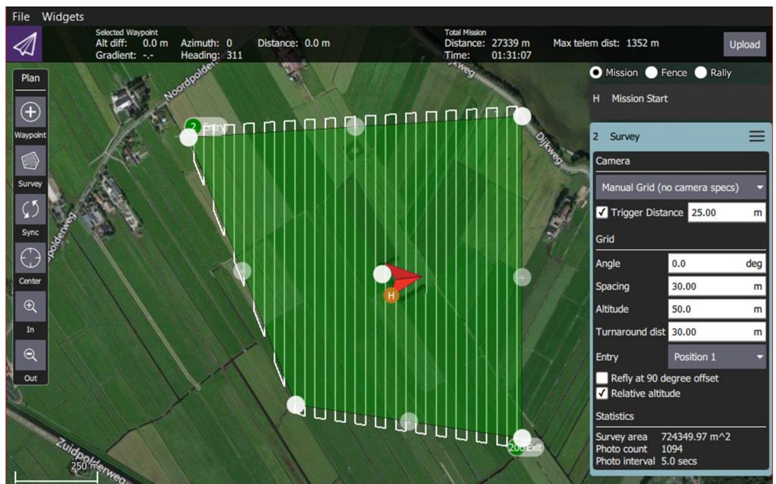
- 2 power inputs
- Power module to measure current and voltage
- 14 servo motors outputs
- Pitot probe and external compass on the I²C protocol
- GPS and external magnetometer
- RC receiver
- Telemetry 433 MHz



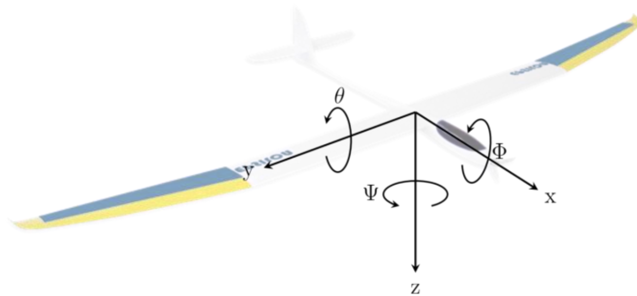
Ground control station : QGroundControl

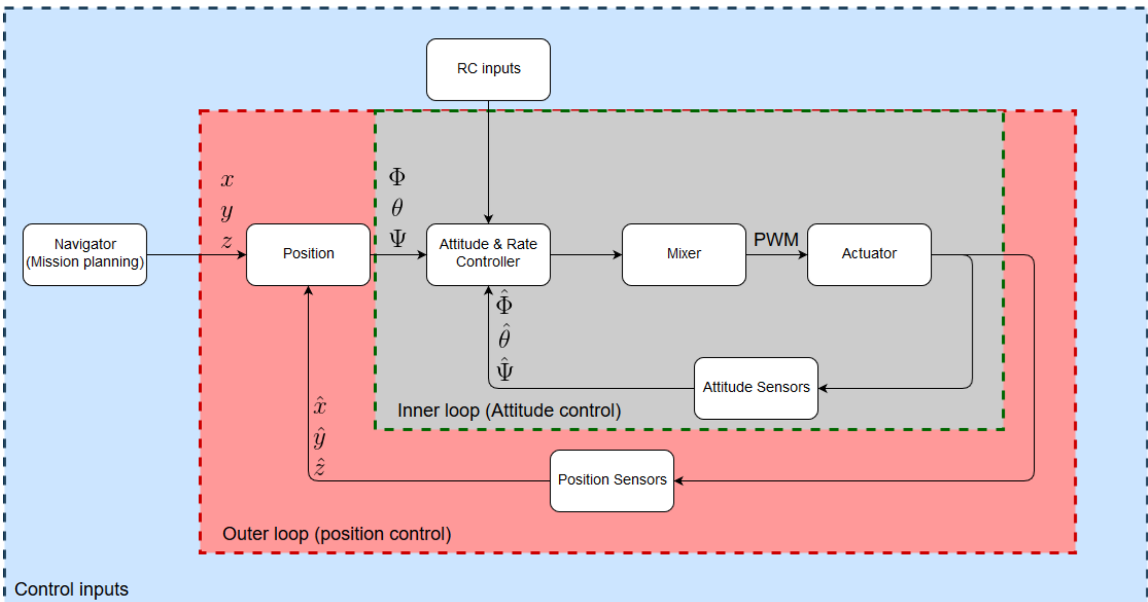
- Open source software
- Use Mavlink UAV communication protocol
- Plan, save and load autonomous missions
- Download and analyze mission logs



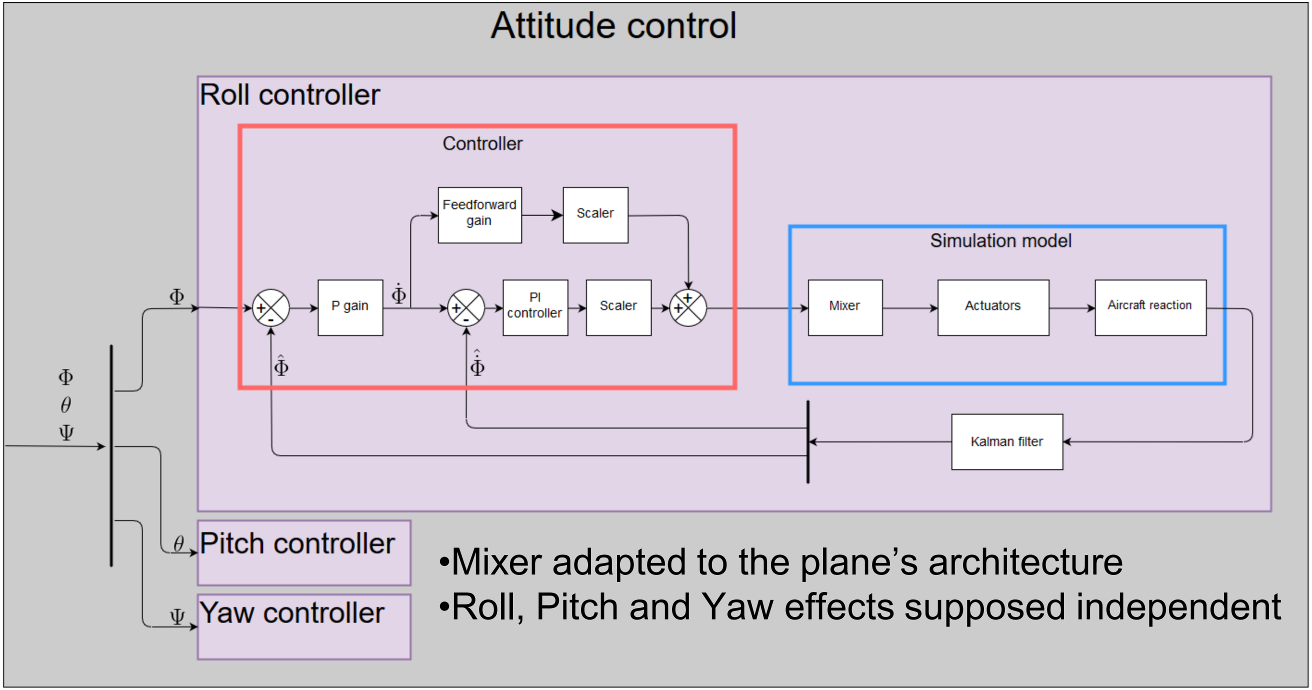


Px4 Flight control





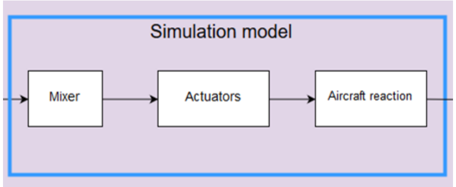
$\hat{x}$: Estimate of x from an EKF



Steps:

1. Model identification
2. Control synthesis

Model identification : roll example



- Linearize the nonlinear mathematical model
- Disconsider interaxes-coupling
- Nominal flying conditions

$$\frac{\Delta \text{roll}}{\Delta \text{aileron}} = \frac{\mathbf{K}}{s(s+\mathbf{p})}$$

Two proposed methods:

- With flight data
- Through computer simulations

Modelling procedure - roll

Identify a transfer function

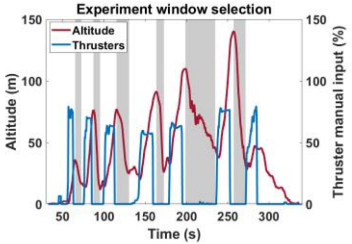
$$\frac{\Delta \text{roll}}{\Delta \text{aileron}} = \frac{\mathbf{K}}{s(s+\mathbf{p})}$$

- **In-flight procedure**
- Off-flight procedure

In-flight:

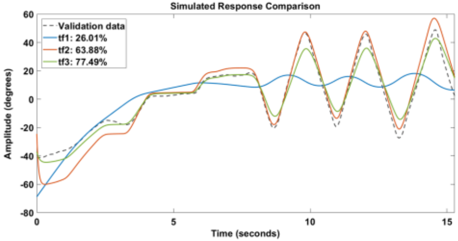
1. Arbitrarily excite the ailerons

1. Select data from log files



Separate manoeuvers from experiments:
Fall with deactivated thrusters

1. Identify a transfer function



$$\frac{\Delta \text{roll}}{\Delta \text{aileron}} = \frac{64.68}{s(s+18.6)}$$

$$V_a = 11.04 m/s$$

Modelling procedure - roll

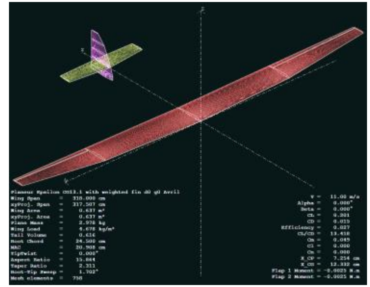
Identify a transfer function

$$\frac{\Delta \mathrm{roll}}{\Delta \mathrm{aileron}} = \frac{\mathbf{K}}{s(s+\mathbf{p})}$$

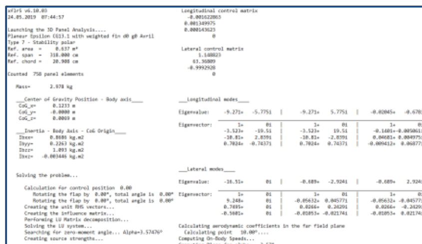
- In-flight procedure
- **Off-flight procedure**

Off-flight:

1. Build a CAD model



1. Simulate and obtain aerodynamic coefficients



```
xflr5 v6.10.03
24.05.2019  07:44:57

Launching the 3D Panel Analysis....
Planeur Epsilon C613.1 with weighted fin d0 g0 Avril
Type 7 - Stability polar
Ref. area  =     0.637 m²
Ref. span  =   318.000 cm
Ref. chord =    20.908 cm

Counted  758 panel elements

   Mass=       2.978 kg

   ___Center of Gravity Position - Body axis___
    CoG_x=      0.1233 m
    CoG_y=     -0.0000 m
    CoG_z=      0.0069 m

   ___Inertia - Body Axis - CoG Origin___
    Ibxx=      0.8686 kg.m2
    Ibyy=      0.2263 kg.m2
    Ibzz=       1.093 kg.m2
    Ibxz=   -0.003446 kg.m2

   Solving the problem...

      Calculation for control position  0.00
         Rotating the flap by  0.00°, total angle is  0.00°
         Rotating the flap by  0.00°, total angle is  0.00°
      Creating the unit RHS vectors...
      Creating the influence matrix...
      Performing LU Matrix decomposition...
      Solving the LU system...
      Searching for zero-moment angle... Alpha=3.57476°
      Creating source strengths....

Longitudinal control matrix
   -0.001622863
    0.001349975
    0.000143623
              0

Lateral control matrix
     1.148823
     63.36809
   -0.9992928
            0

___Longitudinal modes___

Eigenvalue:    -9.271+  -5.775i  |   -9.271+   5.775i  |  -0.02045+  -0.678i
Eigenvector:        1+       0i  |        1+       0i  |         1+       0i
               -3.523+   -19.5i  |   -3.523+    19.5i  |  -0.1401+-0.005061i
               -10.81+   2.839i  |   -10.81+  -2.839i  |  0.04681+ 0.004975i
               0.7024+ -0.7437i  |   0.7024+  0.7437i  | -0.009412+ 0.06877i

___Lateral modes___

Eigenvalue:    -16.51+       0i  |   -0.689+  -2.924i  |   -0.689+   2.924i
Eigenvector:        1+       0i  |        1+       0i  |        1+       0i
                9.248+       0i  | -0.05632+ 0.04577i  | -0.05632+ -0.04577i
               0.7495+       0i  |   0.0266+  0.2429i  |   0.0266+  -0.2429i
              -0.5601+       0i  | -0.01053+ -0.02174i | -0.01053+  0.02174i

Calculating aerodynamic coefficients in the far field plane
  Calculating point   10.00°....
Computing On-Body Speeds...
Computing Plane for alpha=  3.57°
```

XFLR5 Stability analysis log

$$K = 0.5\boxed{\rho V_a^2 SbC_{p_{\delta_a}}}$$

$$p = 0.25\boxed{\rho V_a Sb^2 C_{p_p}}$$

1. Identify a transfer function

$$\frac{\Delta \mathrm{roll}}{\Delta \mathrm{aileron}} = \frac{63.40}{s(s+16.75)}$$

$$V_a = 11.46m/s$$

Procedure comparison

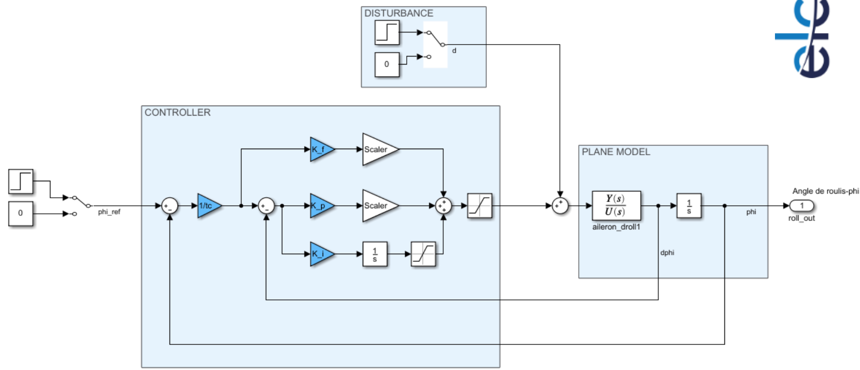
Use of open source tools and simple to put in application.

Useful for all fixed-wing planes.

	In-flight	Off-flight
Pros	• Speed dependent model • Freedom on model choice	• No weather issues • Tools available on the development of the drone
Cons	• User dependent • Sensor dependent	• Prone to design simplifications • Single airspeed model
$\frac{\Delta \text{roll}}{\Delta \text{aileron}}$	$\frac{64.68}{s(s+18.6)}$ $V_a = 11.04 m/s$	$\frac{63.40}{s(s+16.75)}$ $V_a = 11.46 m/s$

Attitude controller simulation

- Airspeed-scaled PID and FF
- Can be tuned for robustness constraints



Constant speed model

Optimised unitary closed-loop step response

- Settling time : 0.23s
- No overshoot

Further work in control

- Plane model + PX4 controller in Matlab for PID tuning
  - Endurance constraints
  - H-infinity based controller
- Other control laws
  - Adaptive control
- Refine the model
  - Varying airspeed
  - Inter-axes couplings

Aim: Create a control strategy that is *robust* to *load variations* and *windspeed*, change the given PX4 control structure to take into account *airspeed*, *pressure*, varying *plane mass*...

Thank you for your attention!