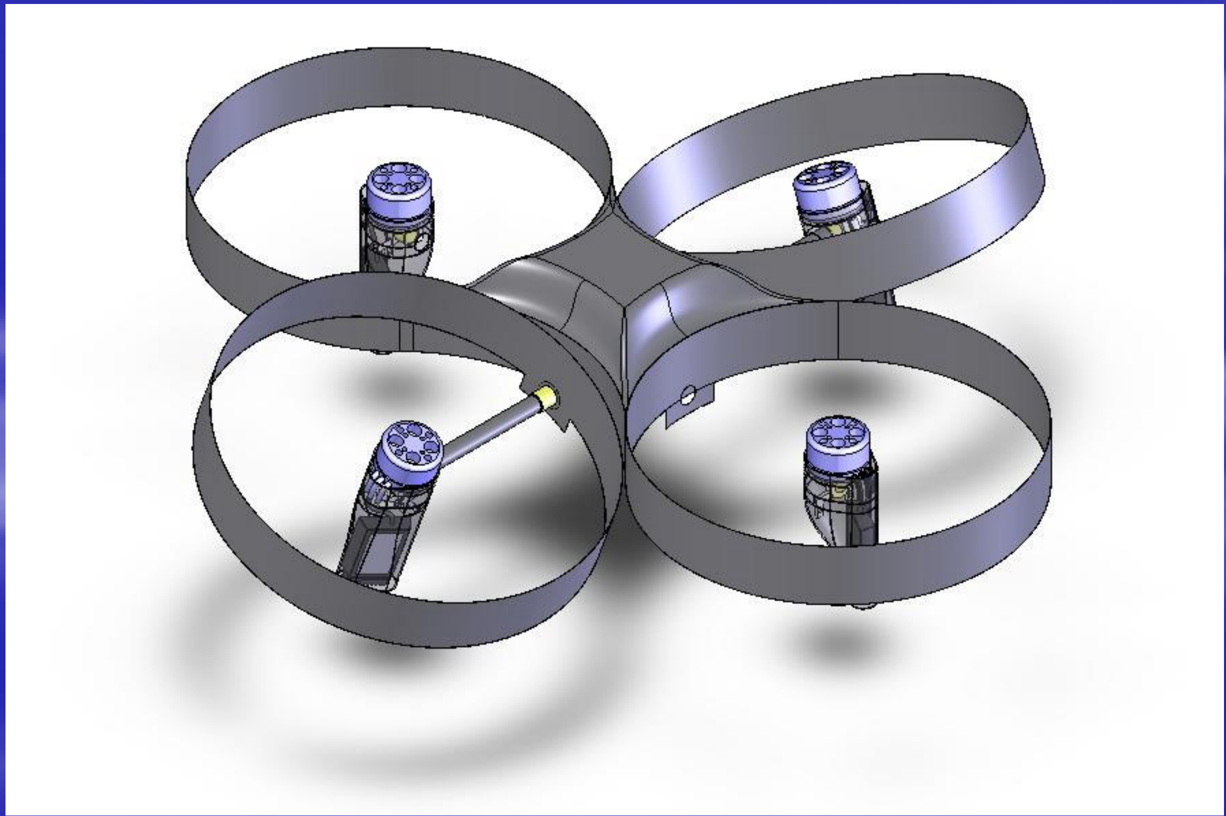
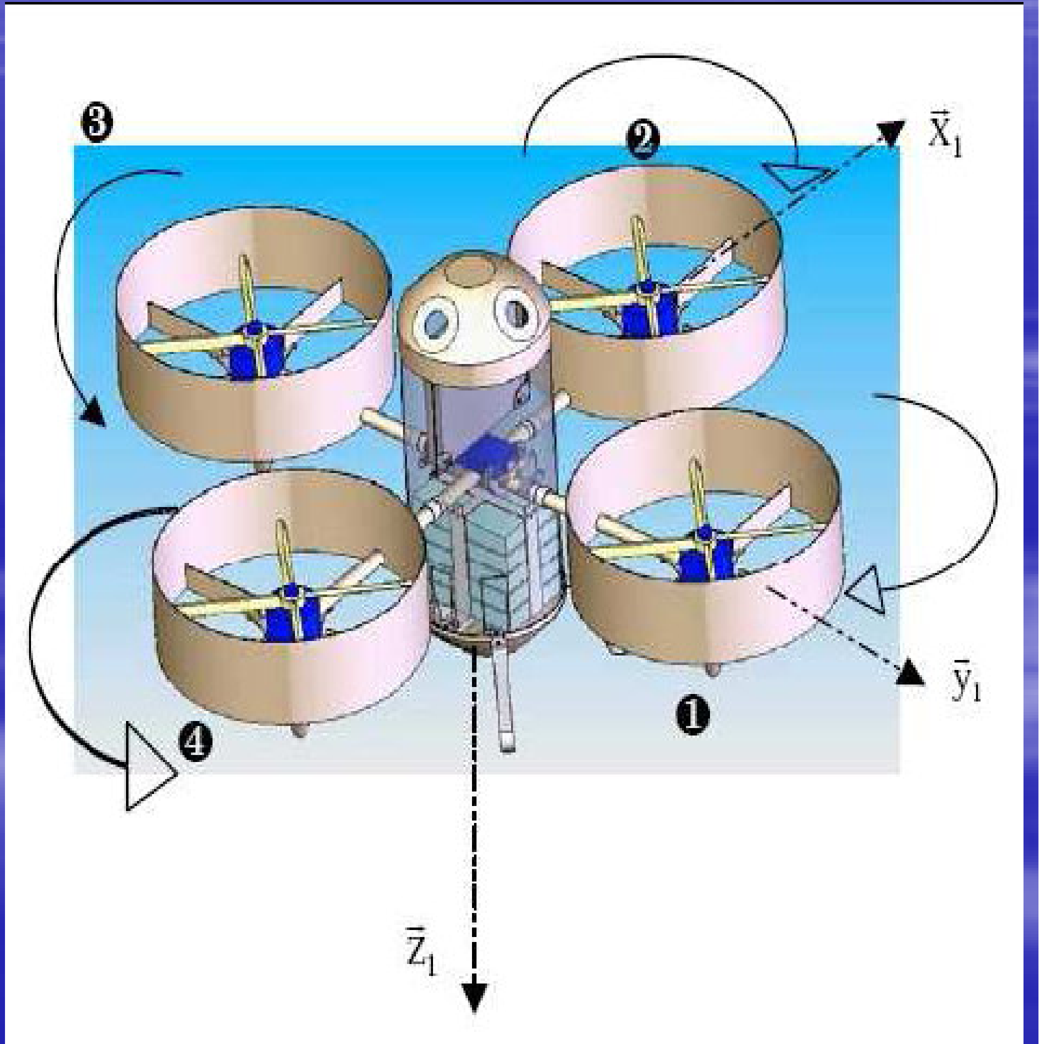
Modelling and development of a quadrotor UAV



Design of the XSF

- Designed in the shape of a cross.
- Each end of the cross has a rotor including an electric brushless motor.
- Rotors (1) and (2) turn clockwise, while rotors (3) and (4) turn counterclockwise.
- Swivelling of the supports of motors (1) and (4) around their pitching axis.
- Embedded sensors and microcontroller located in the centre of the drone.



Objectives and Constraints

- Small Unmanned Aerial Vehicle - around 68 cm
- Light weighted – around 2kg
- Maneuverable
- Small UAV designed to inspection and surveillance
- Platform must be able to perform stationary flight in order to obtain clear images coming from an embedded camera

Objectives and Constraints

- It is necessary to work in inaccessible and often narrow spaces
- The main expected applications are:
  - Inspection underneath of bridges and its supports
  - Inspection of buildings or structures, specially with non-smooth surfaces, like monuments or industrial plants
  - Indoors supervision and inspection such as inside pipes or tanks

Sensors

- Embedded sensors :
  - Inertial Measurement Unit provides angles, angular velocity and accelerations.
  - 4 ultra sonic range finders - distances to obstacles and ground.
  - Camera – image return to human pilot.

- GPS as an option, but not reliable (indoors applications).

- Additional problem -> Linear speed not measured but needed for stabilization and control. Solution -> nonlinear observer.

XSF dynamical model

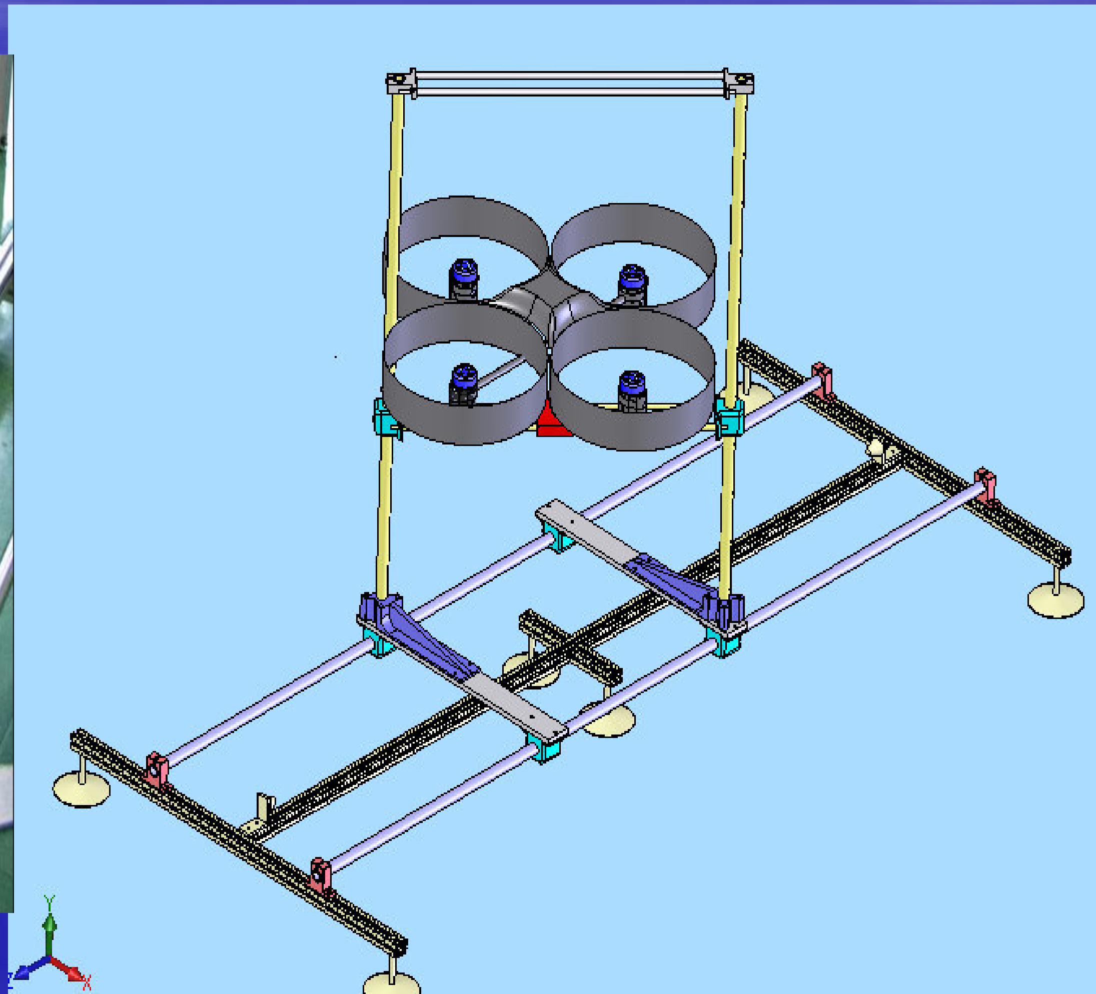
$$\dot{x} = \cos\theta\cos\psi\, u + (\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi)v$$
$$\quad + (\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)w$$
$$\dot{y} = \cos\theta\sin\psi\, u + (\sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi)v$$
$$\quad + (\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)w$$
$$\dot{z} = -\sin\theta\, u + \sin\phi\cos\theta\, v + \cos\phi\cos\theta\, w$$

$$\dot{\phi} = p + (\sin(\phi)q + \cos(\phi)r)\tan(\theta)$$
$$\dot{\theta} = \cos(\phi)q - \sin(\phi)r$$
$$\dot{\psi} = (\sin(\phi)q + \cos(\phi)r)\cos(\theta)^{-1}$$

$$\dot{u} = (-qw + rv - g\sin\theta) - \frac{k_T}{m}(\omega_1^2\sin\beta_1 + \omega_3^2\sin\beta_3)$$
$$\dot{v} = (-ru + pw + g\sin\phi\cos\theta)$$
$$\dot{w} = (-pv + qu + g\cos\phi\cos\theta) - \frac{k_T}{m}(\omega_1^2\cos\beta_1 + \omega_2^2 + \omega_3^2\cos\beta_3 + \omega_4^2)$$

$$I_{xx}\dot{p} = -l_b k_T(\omega_1^2\cos\beta_1 - \omega_3^2\cos\beta_3) - (I_{zz} - I_{yy})rq$$
$$\quad - qI_r(\omega_1\cos\beta_1 + \omega_2 + \omega_3\cos\beta_3 + \omega_4)$$
$$I_{yy}\dot{q} = l_b k_T(\omega_2^2 - \omega_4^2) - (I_{xx} - I_{zz})rp - rI_r(\omega_1\sin\beta_1 + \omega_3\sin\beta_3)$$
$$\quad + pI_r(\omega_1\cos\beta_1 + \omega_2 + \omega_3\cos\beta_3 + \omega_4) + k_M(\omega_3^2\sin\beta_3 - \omega_1^2\sin\beta_1)$$
$$I_{zz}\dot{r} = -l_b k_T(\omega_1^2\sin\beta_1 - \omega_3^2\sin\beta_3) - (I_{yy} - I_{xx})pq$$
$$\quad + qI_r(\omega_1\sin\beta_1 + \omega_3\sin\beta_3) + k_M(\omega_3^2\sin\beta_3 + \omega_4^2 - \omega_1^2\sin\beta_1 - \omega_2^2)$$

The XSF and its test bed



Observer and Control Schemes

- Necessarily embedded! Communication with ground station may be lost.
- Algorithms still under development.
- First version - Robust linear controller.
- Expect to be replaced by nonlinear possibly adaptive controllers.
- Problem – Difficult to stabilize without linear velocity.
- Proposed solution - To estimate with a nonlinear adaptive observer (under development).
- Better robustness compared to Kalman Filter in simulations.

Hardware architecture
Sensors

Angles : Roll(x), Pitch(y), Yaw(z)
Instantaneous acceleration θ_x, θ_y, θ_z
Compensate angular rates ω_x, ω_y, ω_z

Triaxial accelerometers, magnetometers and angular rate sensors to measure static and dynamic orientation

RS232, 38400bps

ARM7TDMI
32 BITS RISC

I2C bus, 400kbps

Ultrasonic range finder (3cm-6m), I2C™ interface.

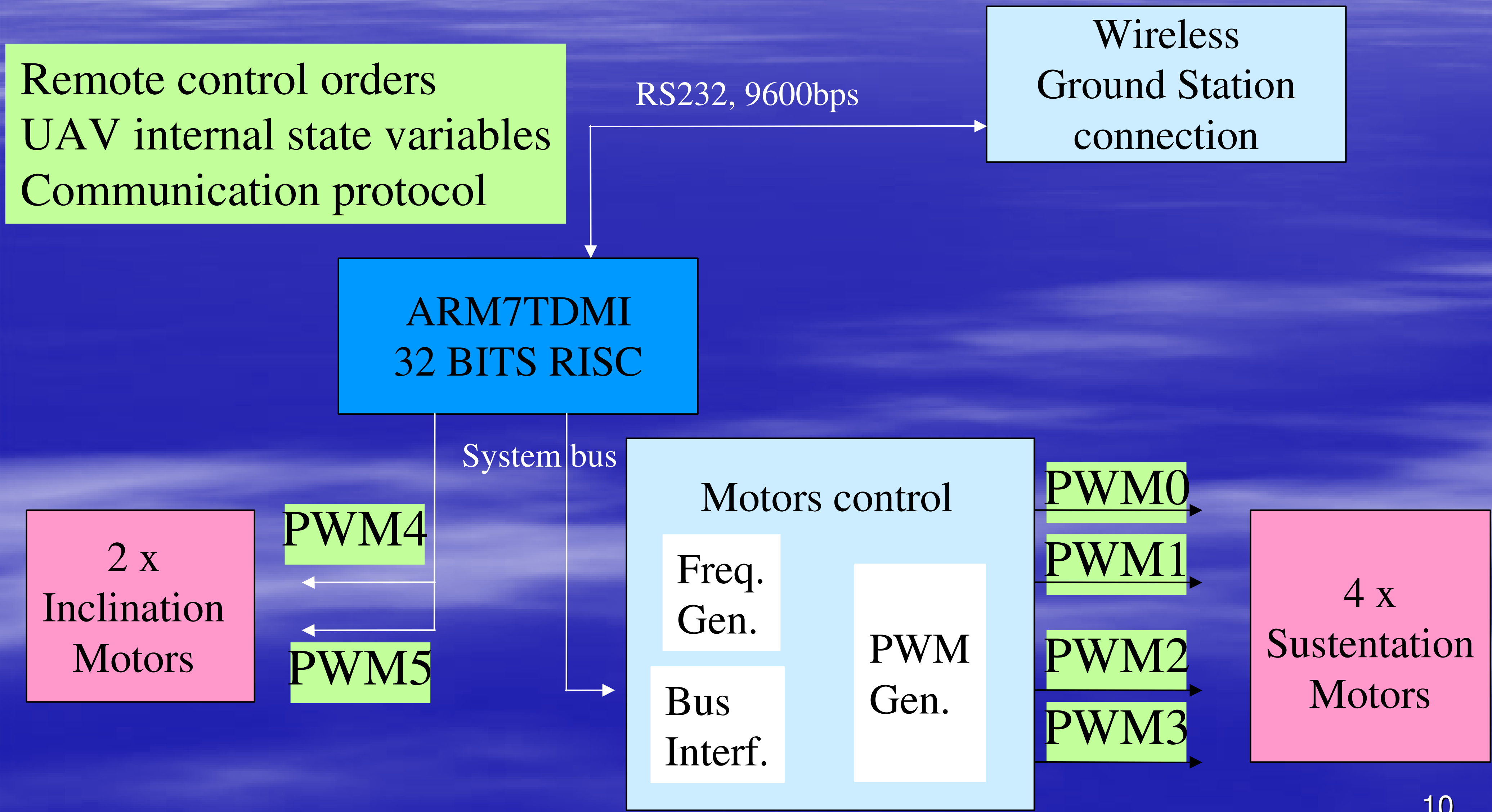
1 x US
range finder

Distance Hground

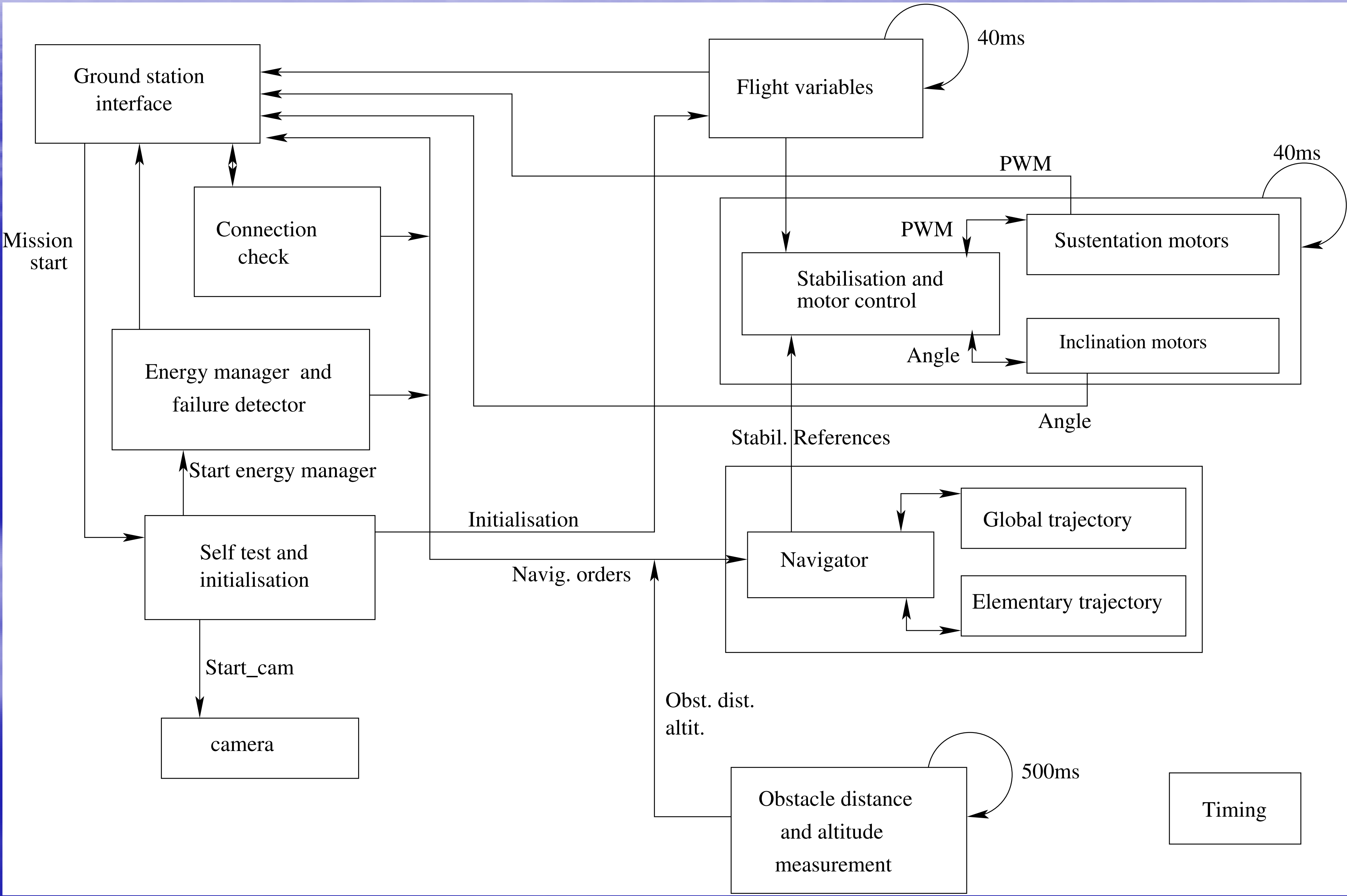
3 x US
range finders

Distances : Dleft, Dright, Dfront

Hardware architecture Actuators interface and WGS connection



Software architecture
Functional diagram

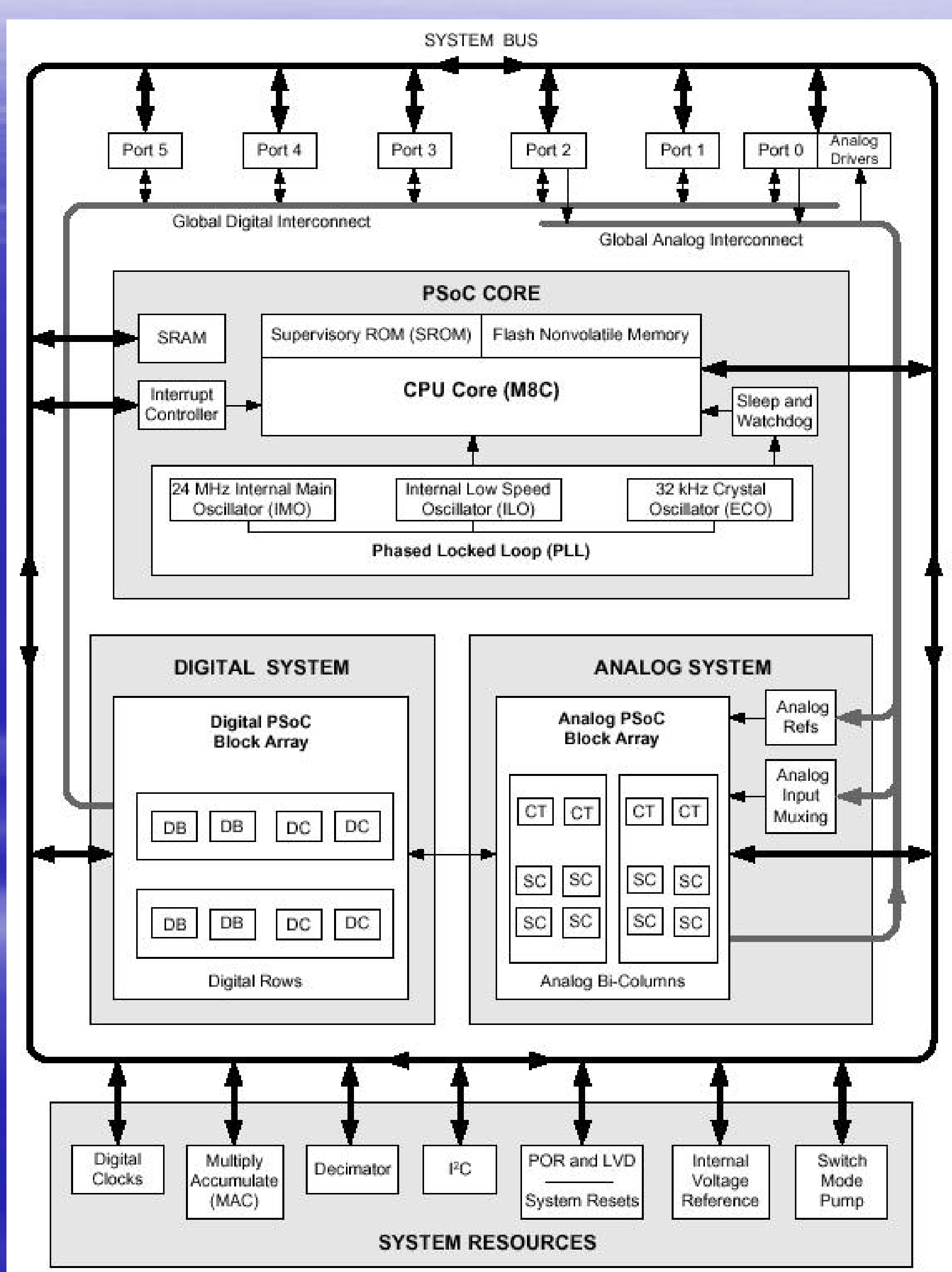


Software architecture - RTOS

- eCos : embedded Configurable operating system
  - Allows to build a real-time operating system for a specific hardware architecture
  - Multiple hardware platforms supported thanks to the Hardware Abstraction Layer (HAL)
  - For the XSF : configured to work with the Phytec ARM7/LPC-2294 card

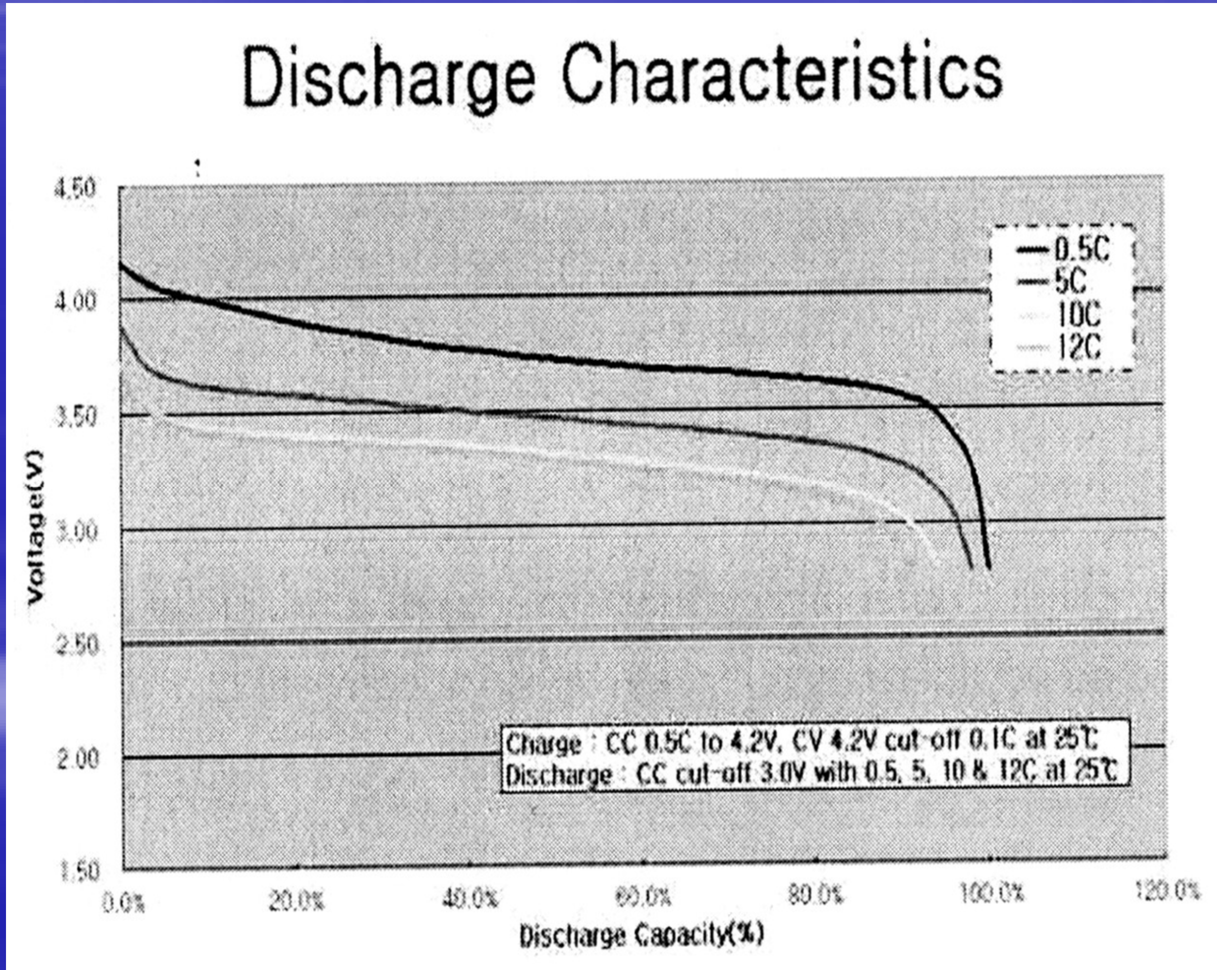
Energy manager

- Energy measurement :
  - Current sensor
  - Voltage sensor
  - Elapsed time from mission start
- Use of PSoC Technology



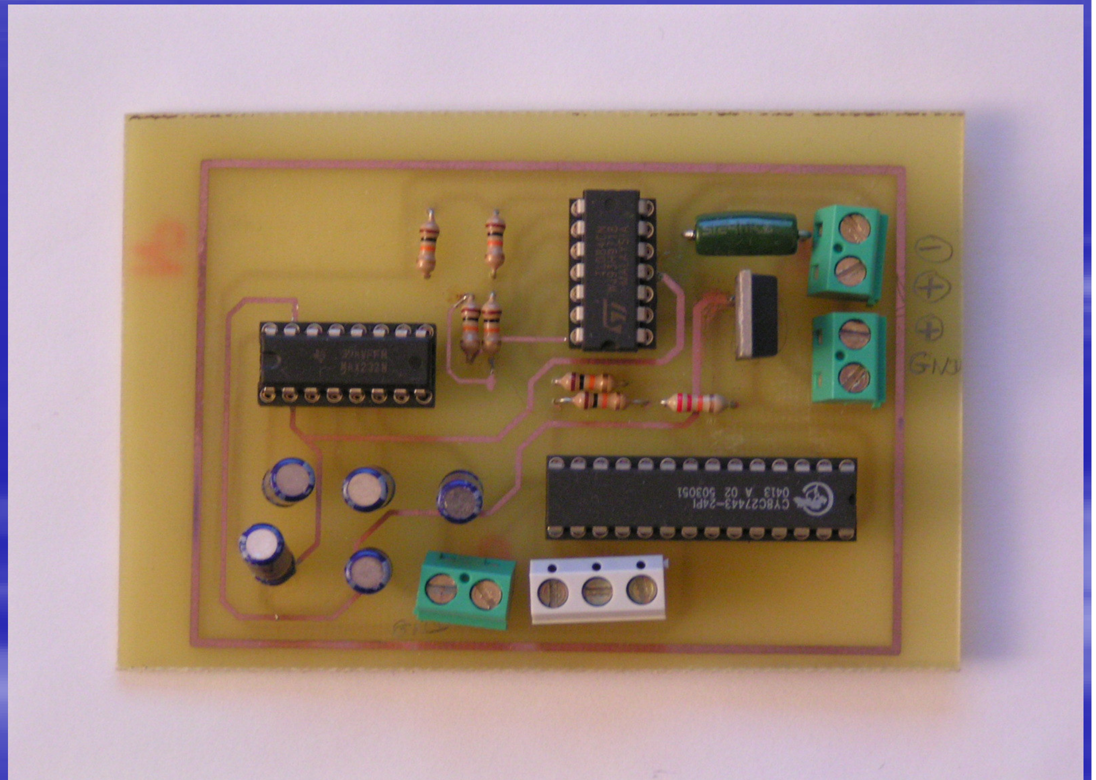
Energy manager

Estimates remaining energy in battery cells based on discharge function of a polymer-lithium cell

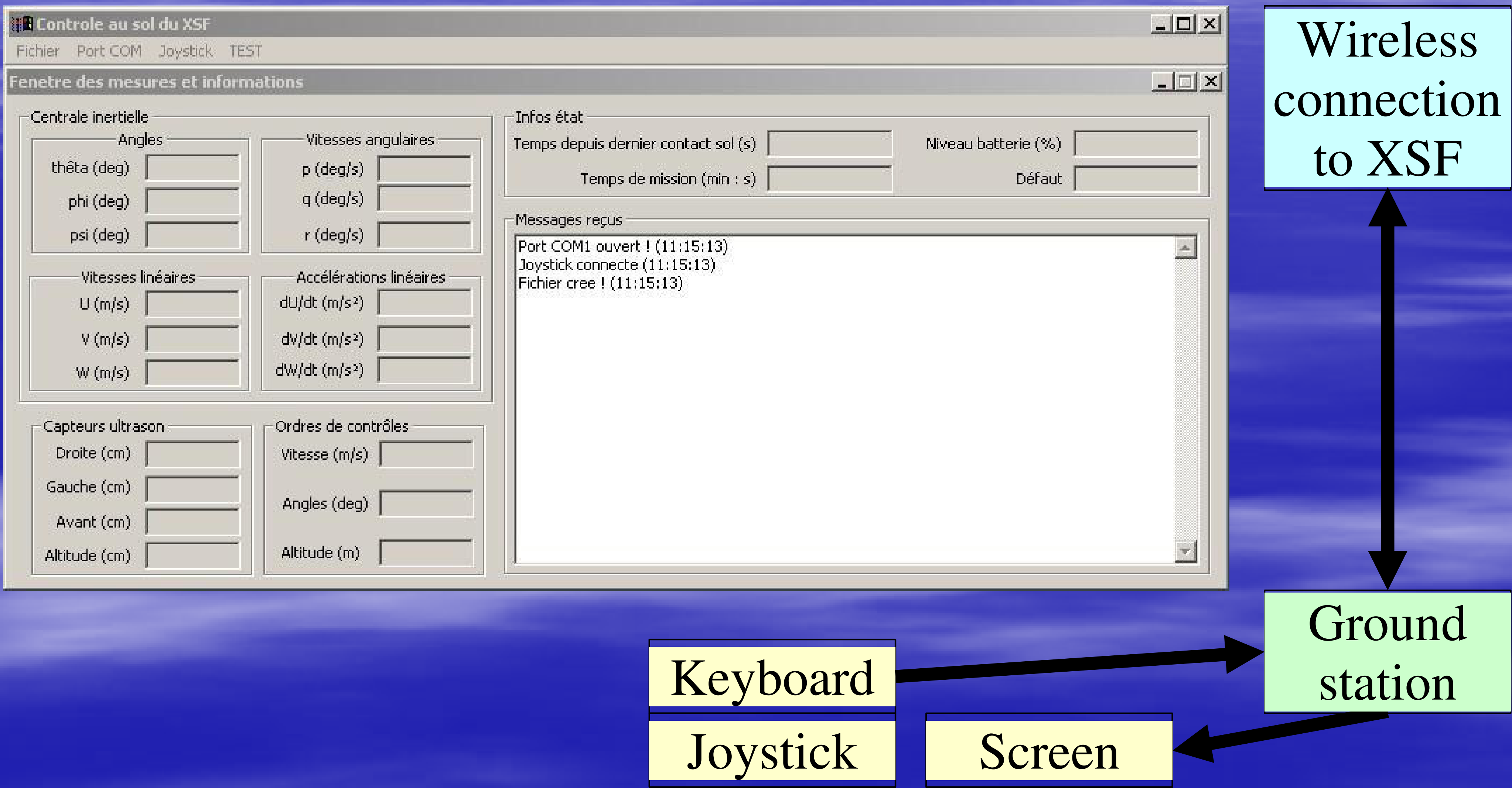


Energy manager

- Measurement of energy used by UAV during discharge
- Measurement of energy during charging phase
- 3 output signals
  - Battery charged (100%)
  - Battery discharged
    - 20% remaining
    - Fully discharged



Ground station



Conclusions

•Physical structure operational

•XSF flies on its test bed

•Sensors are read in real time

•Ground base operational

•Observer tested by simulations - will be soon implemented on the test bed

•Control system under development

•Decision structure under development