Conception et commande d'un robot parallèle volant

Journée technique "drones et manipulation"

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Aerial robotics

Flying UAV + Robotic device

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New generation of aerial robots

Several Approaches

- UAV + 1 DoF actuated mechanism
- UAV + serial or parallel robot
- Several UAVs + cable load transportation

Several Approaches

- **UAV + 1 DoF actuated mechanism**
  → *Limited in payload and manipulation abilities*

- UAV + serial or parallel robot

- Several UAVs + cable load transportation

Figure : Quadrotor + 1 DoF manipulator (University of Pennsylvania)

Several Approaches

- UAV + 1 DoF actuated mechanism
- **UAV + serial or parallel robot**
  (+) *Better manipulation ability*
  (−) *Autonomy/payload*
  additional embedded motors
  Stabilization while operating
- Several UAVs + cable load transportation

Figure : UAV + robotic arm manipulator (LAAS-CNRS)

Several Approaches

- UAV + 1 DoF actuated mechanism
- UAV + serial or parallel robot
- **Several UAVs + cable load transportation**
  (+) *Large objects transportation*
  (−) *Requires operator*
  Cannot apply pushing forces
  Operation under the drones only

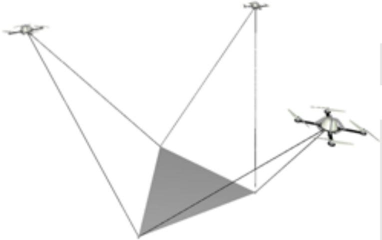
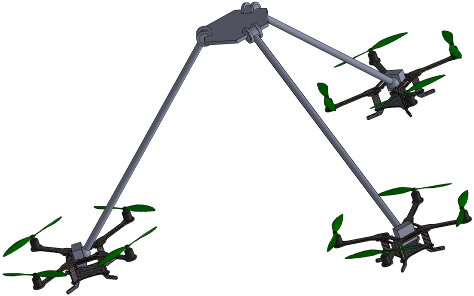


Figure : FlyCrane project (LAAS-CNRS)

A new concept in aerial robotics

Flying robot inspired from rigid parallel manipulators

Several UAVs + Passive kinematic chain



A new concept in aerial robotics

Flying robot inspired from rigid parallel manipulators

Several UAVs + Passive kinematic chain

- **Reconfiguration:** Tasks under and over the drones
- **Efforts are spread** over several drones
- **No additional embedded motors**
- **Effector away** from the drones
- Large choice of **leg topology**
- Advantages of the decoupling properties?

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Study case

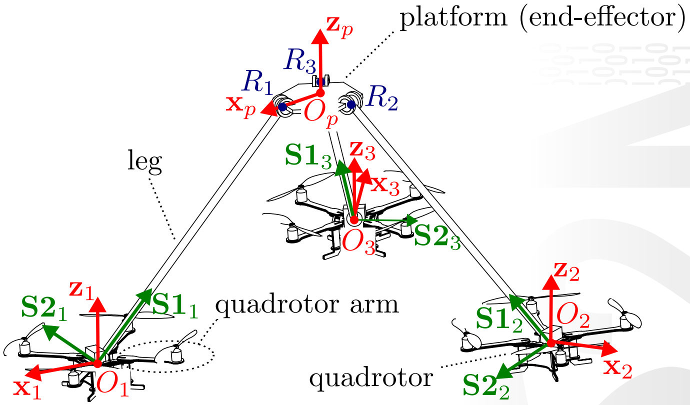


Figure : A flying parallel robot with three quadrotors

Study case

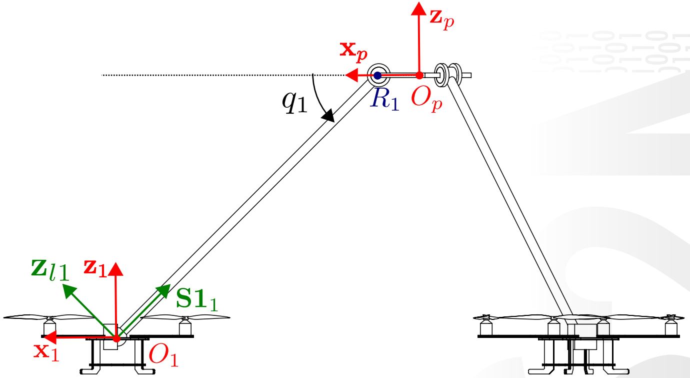
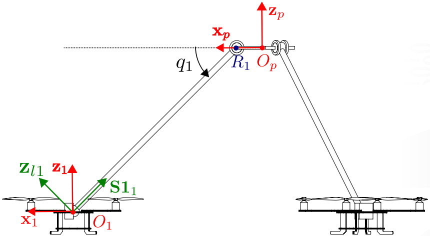


Figure : Side view of the flying parallel robot

Kinematic parameters



Generalized coordinates $\mathbf{q}$:

- $x_p, y_p, z_p, \phi_p, \theta_p, \psi_p$ position and orientation coordinates of the moving platform;
- q_1, q_2, q_3 the relative angle between the platform plane and leg
- $\phi_1, \theta_1, \psi_1, \phi_2, \theta_2, \psi_2, \phi_3, \theta_3, \psi_3$ the orientation coordinates of the drones

Robot dynamic model

Input/Output analysis

- Generalized coordinates **q** is a 18-dimensional vector
- Three 4-dimensional input wrenches

18 d.o.f. for 12 independant inputs

Under-actuation as for a classic quadrotor $\Rightarrow$ similar decoupling?

Splitting the dynamic model

Quadrotor dynamic model

Translation coordinates $\boldsymbol{\xi}$ controlled by thrust $\mathbf{t}$

$$\mathbf{R}(\eta)\mathbf{t} = m\ddot{\boldsymbol{\xi}} - m\mathbf{g}$$

Angular velocities $\boldsymbol{\omega}$ controlled by torques $\boldsymbol{\tau}$

$$\boldsymbol{\tau} = \boldsymbol{\Sigma}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \boldsymbol{\Sigma}\boldsymbol{\omega}$$

Flying robot dynamic model

Splitting the dynamic model

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Flying robot dynamic model

Passive chain coordinates $\mathbf{q}_p$ controlled by thrust $\mathbf{t}$

$$\mathbf{M}\ddot{\mathbf{q}}_p + \mathbf{c} = \mathbf{J}^T\mathbf{R}_t\mathbf{t}$$

Splitting the dynamic model

Quadrotor dynamic model

Translation coordinates $\boldsymbol{\xi}$ controlled by thrust $\mathbf{t}$

$$\mathbf{R}(\eta)\mathbf{t} = m\ddot{\boldsymbol{\xi}} - m\mathbf{g}$$

Angular velocities $\boldsymbol{\omega}$ controlled by torques $\boldsymbol{\tau}$

$$\boldsymbol{\tau} = \boldsymbol{\Sigma}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \boldsymbol{\Sigma}\boldsymbol{\omega}$$

Flying robot dynamic model

Passive chain coordinates $\mathbf{q}_p$ controlled by thrust $\mathbf{t}$

$$\mathbf{M}\ddot{\mathbf{q}}_p + \mathbf{c} = \mathbf{J}^T\mathbf{R}_t\mathbf{t}$$

Attitude coordinates $\boldsymbol{\omega}_i$ controlled by torques $\boldsymbol{\tau}_i$

$$\boldsymbol{\tau}_i = \boldsymbol{\Sigma}_i\dot{\boldsymbol{\omega}}_i + \boldsymbol{\omega}_i \times \boldsymbol{\Sigma}_i\boldsymbol{\omega}_i$$

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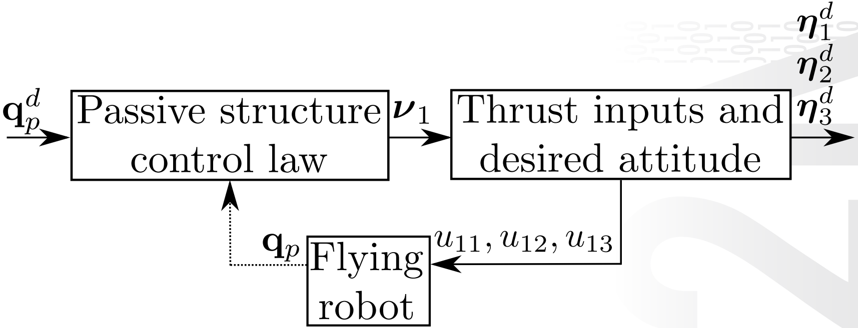
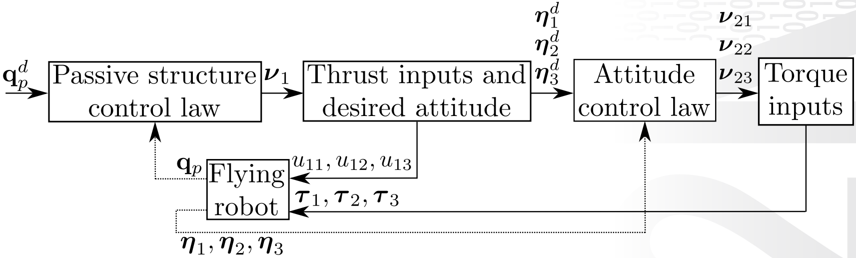
Passive chain control law



Computed torque control law for the passive chain

Attitude control law



Sliding mode control law for attitude

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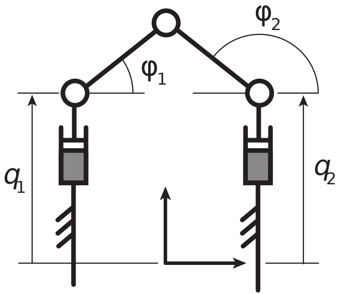
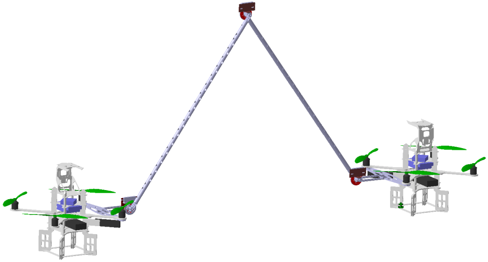
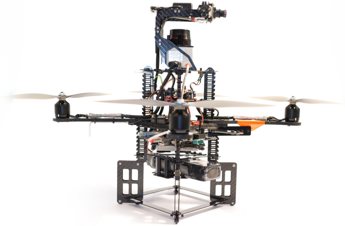
Prototype presentation





Available equipment

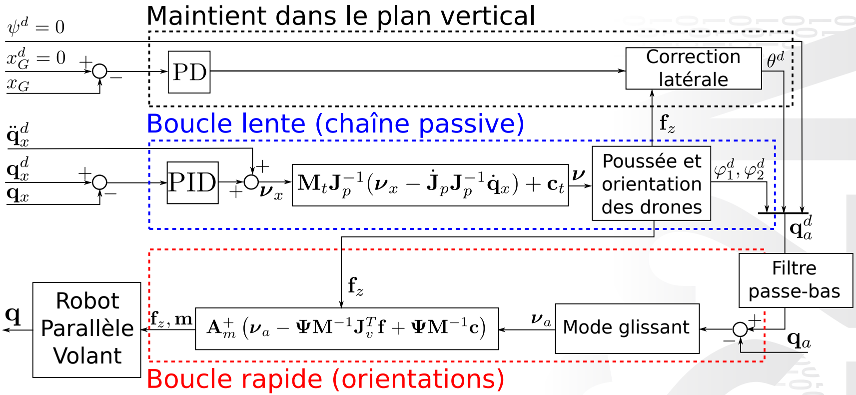
2 PELICAN from ASCTEC/INTEL



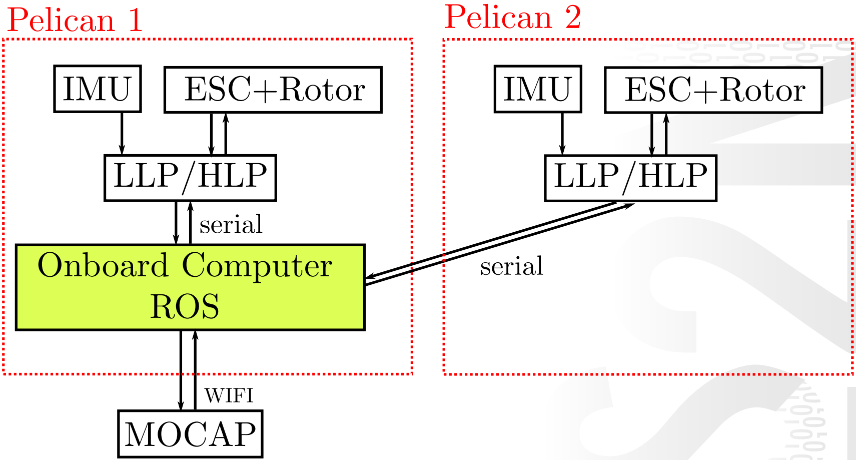
QUALISYS MOCAP system

- 8 cameras
- Position capture at 250 Hz

Controller


Maintient dans le plan vertical
$\psi^d = 0$
$x_G^d = 0$
x_G
PD
Correction latérale
θ^d
Boucle lente (chaîne passive)
$\mathbf{f}_z$
$\ddot{\mathbf{q}}_x^d$
$\mathbf{q}_x^d$
$\mathbf{q}_x$
PID
$\boldsymbol{\nu}_x$
$\mathbf{M}_t\mathbf{J}_p^{-1}(\boldsymbol{\nu}_x - \dot{\mathbf{J}}_p\mathbf{J}_p^{-1}\dot{\mathbf{q}}_x) + \mathbf{c}_t$
$\boldsymbol{\nu}$
Poussée et orientation des drones
φ_1^d, φ_2^d
$\mathbf{q}_a^d$
Filtre passe-bas
$\mathbf{f}_z$
$\mathbf{q}$
Robot Parallèle Volant
$\mathbf{f}_z, \mathbf{m}$
$\mathbf{A}_m^+(\boldsymbol{\nu}_a - \boldsymbol{\Psi}\mathbf{M}^{-1}\mathbf{J}_v^T\mathbf{f} + \boldsymbol{\Psi}\mathbf{M}^{-1}\mathbf{c})$
$\boldsymbol{\nu}_a$
Mode glissant
$\mathbf{q}_a$
Boucle rapide (orientations)

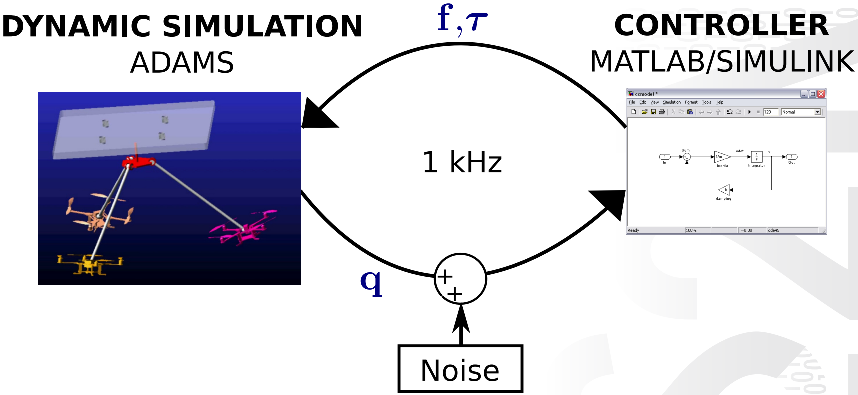
Equipement and communication



Trajectory tracking: "Up" configuration

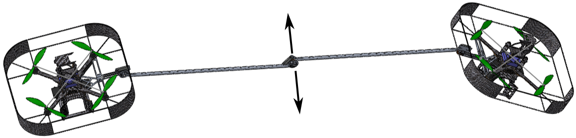
"Down" configuration

Simulator


DYNAMIC SIMULATION
ADAMS
f, τ
CONTROLLER
MATLAB/SIMULINK
1 kHz
q
+
+
Noise

Singularity crossing

- Specific for each passive structure ⇒ Kinematic study
- One uncontrolled DoF when crossing the singularity



- Degeneracy of the dynamic model ⇒ Specific controller

Singularity crossing

Task example

Content

Main contributions

- New concept of a **flying structure with collaborative quadrotors** inspired from **rigid parallel robot**.
- Expression and properties of its **dynamic model**. Design of a **stabilizing control law**.
- Design and experimentation with 2 drones as a **proof of concept**.
- Design of a 3 drones flying parallel robot that allows control of the **6 DoFs** of a platform.

Potential future work

- Experimental prototype with three quadrotors
- Reconfiguration (singularity crossing) in experimental conditions
- Towards manipulation: use legs to actuate a gripper or add a tool to the platform.

Thank you for your attention