

# Physical interaction of aerial robots, from interaction with an object to collaboration with a worker

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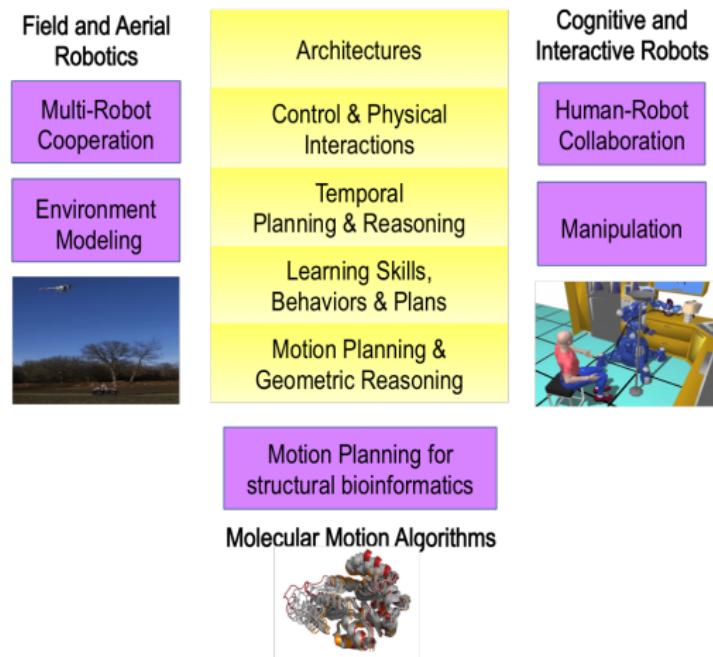
CNRS, LAAS-CNRS, Université de Toulouse, Toulouse, France

<sup>2</sup>RM, Journée Technique : Drones et manipulation, August 30th, 2018



Faculté  
des Sciences  
et d'Ingénierie

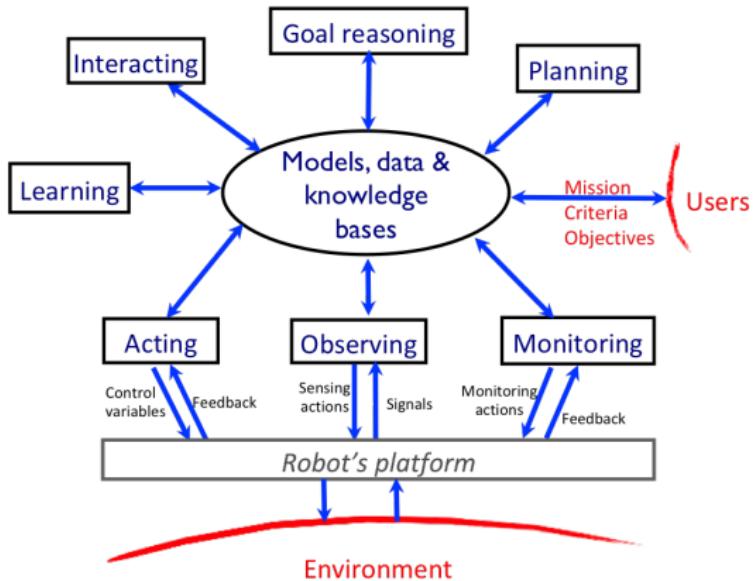
# The RIS Team



**Objective: Combine work on cognitive and interactive robots with aerial robots**

- Decisional and Control Architectures for cognitive robots
- Verification and Validation of Robotic Software Architecture
- Motion and Manipulation Planning
- Human-Robot Cooperation
- Aerial Robotics

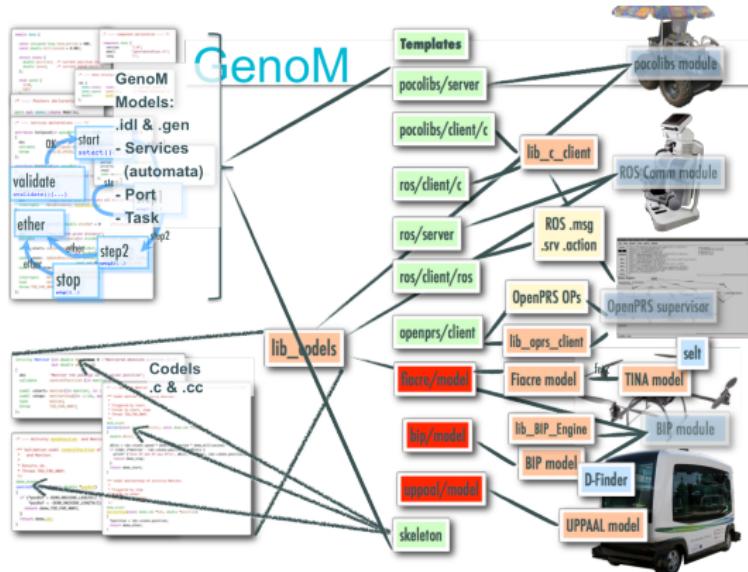
# Decisional and Control Architectures for cognitive robots



## • GenoM

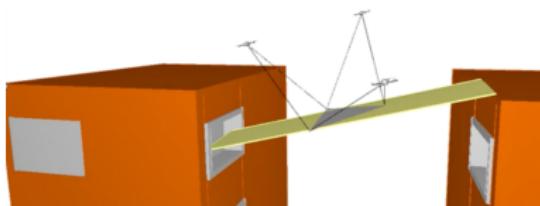
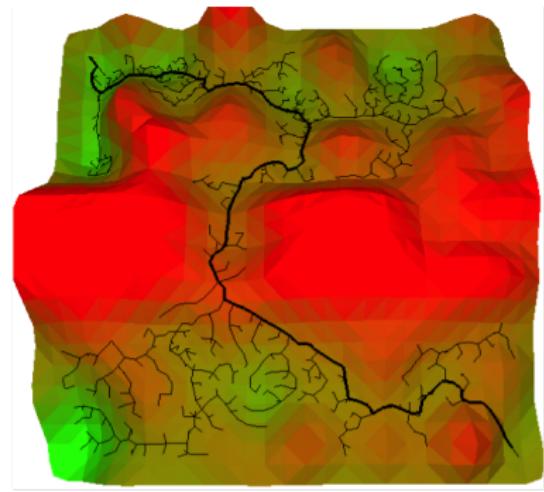
<https://git.openrobots.org/projects/genom3/wiki>

# Verification and Validation of Robotic Software Architecture



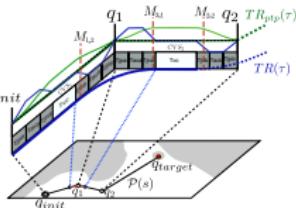
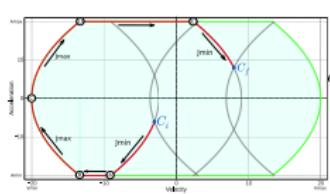
- Check that the system moves safely
- Check that the robot has a consistent perception/action loop

# Motion and Manipulation Planning



- Cost-based motion planning T-RRT algorithm  
[Jaillet L., Cortes J., Siméon T., ICRA 2010]

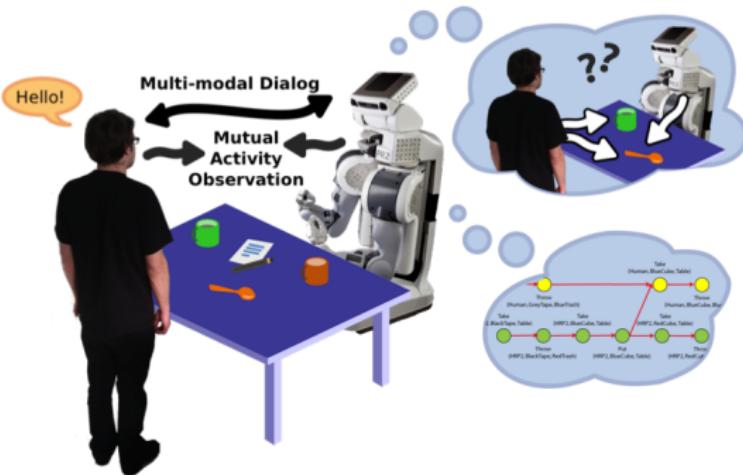
# Trajectory generation



- The trajectories describe the movements
- HRI, but also reliability of machines require at least trajectories functions of class C2
- Series of polynomial functions of 3rd degrees are the simpler functions.
- The softMotion library
  - Jerk, acceleration and velocity bounds
  - Generation and approximation of trajectories
  - Set of tools from planning to control

<https://git.openrobots.org/projects/softmotion/wiki>

# Human-Robot Cooperation



- Human aware motion planning
- Perspective-taking
- geometric reasoning for anchoring facts on human-robot object manipulation

# Aerial Physical Interaction

# Look but don't touch



<https://www.skydroneuavs.com/>

Contact-free Aerial Robotics:

control of maneuvers + visual/onboard perception

# Robot etymology

**ROBOT**



ROBOT



**PHYSICAL  
WORK**

From Czech, from *robita* 'forced labour'.

# Aerial physical interaction



<http://www.aeroworks2020.eu/>

Aerial Robotics:

... + interaction control + perception of forces

# Applications

Any physical operation in:

Tall infrastructures

(buildings, factories, bridges, airplanes, wind turbines,...)



Hardly accessible ground zones

(disaster areas, mountains,...)



# Challenges

## Actuation

forces delivered

10 times

- less accurate
- more limited

than for ground  
robotics

# Challenges

## Actuation

- forces delivered 10 times
- less accurate
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## Couplings

- underactuation
- inertial couplings

# Use Case: AeroArms

## Inspection of industrial pipes



- Crack Detection
- Weld inspection
- Corrosion detection
- Coating thickness
- Metal sorting
- Material properties

proximity sensors: need contact

Probe Type	Surface Inspection Applications					
	Crack detection	Weld inspection	Corrosion detection	Coating thickness assessment	Metal sorting	Material properties
Flat Absolute (with reference coil in bridge)			✓	✓	✓	✓ (3)
Conical Absolute (with reference coil in bridge)	✓	✓ (2)	✓	✓		✓ (3)
Smart-PlusProbe (Anisotropic)	✓	✓ (2)				
Pencil-Probe Absolute 0.9mm	✓ (3)			✓		✓ (4)

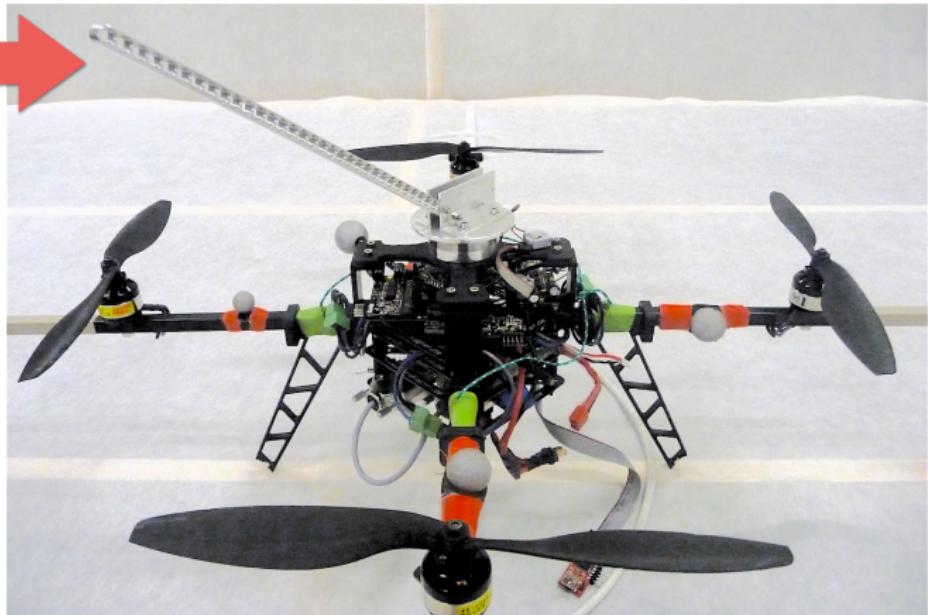
(1) For crack detection in constrained access applications

(2) Suited to accomplish standard BS 1711:2000

(3) For conductivity, heat treatment and porosity assessment

(4) For fine resolution conductivity and porosity measurements

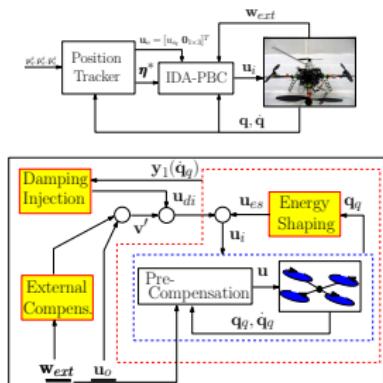
# First Idea: Sensor Rigidly Attached



# Controller + Experiment

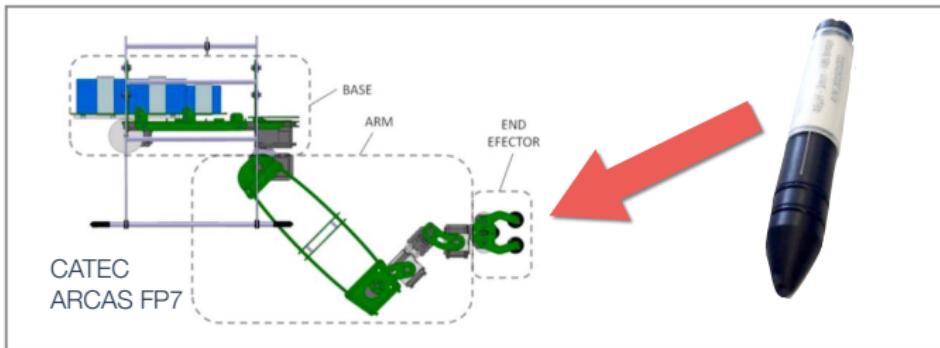
- Nonlinear Control

[Yüksel, Secchi, Bülthoff, **Franchi**, ICRA 2014]

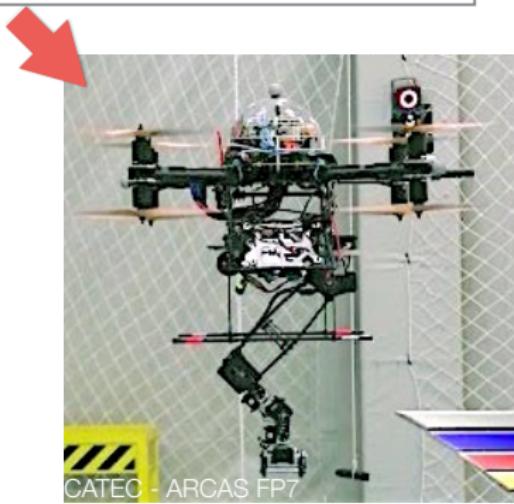
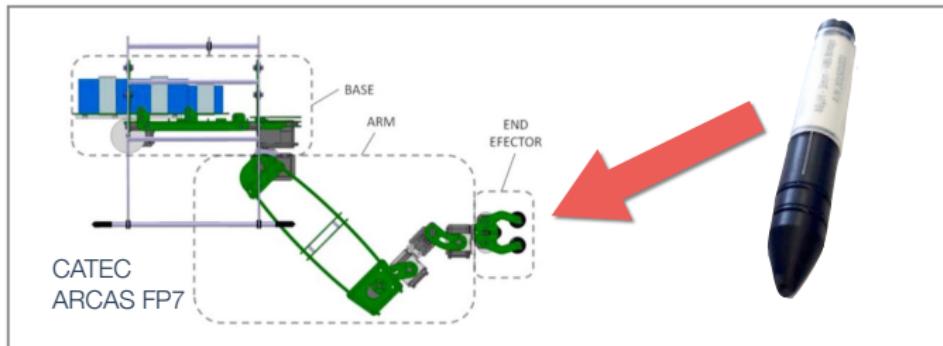


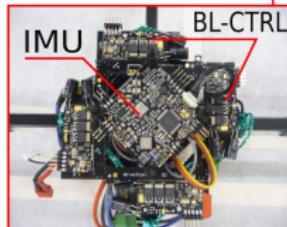
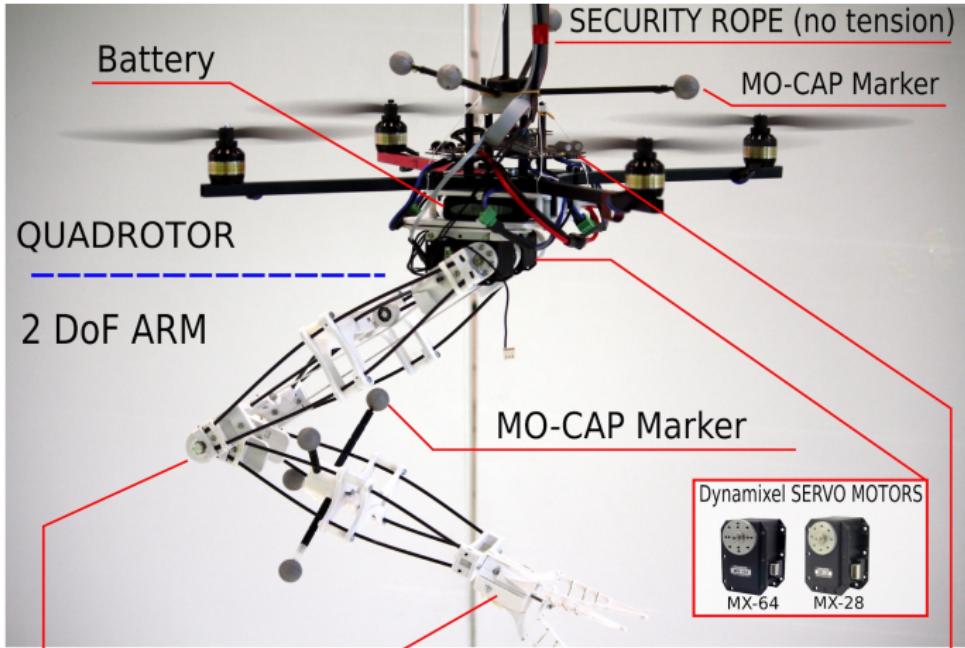
The tip unavoidably swings  
structural limitation (due to underactuation)

# Manipulator for swing compensation?

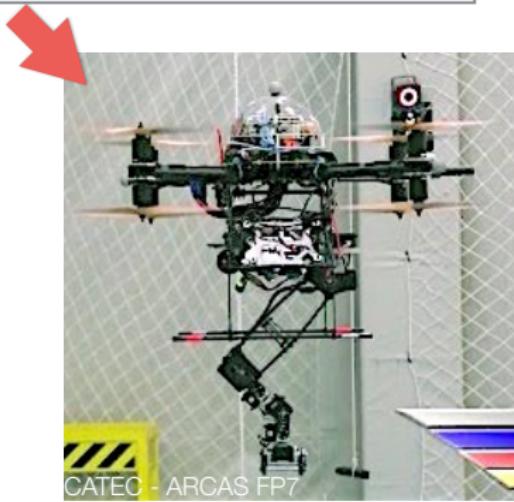
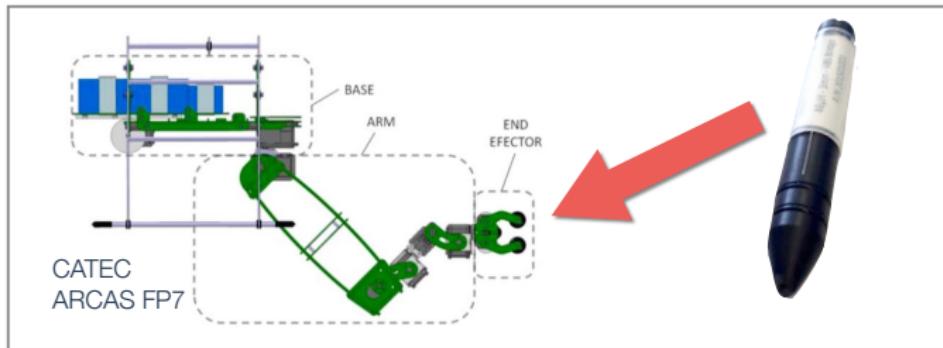


# Manipulator for swing compensation?





# Manipulator for swing compensation?



- Over-complicated
- Wasted Payload
- Expensive

# Normal platforms are “singular”

Only one total thrust direction

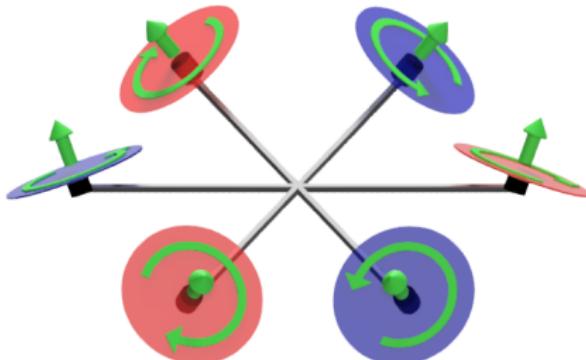


# Normal platforms are “singular”

Only one total thrust direction



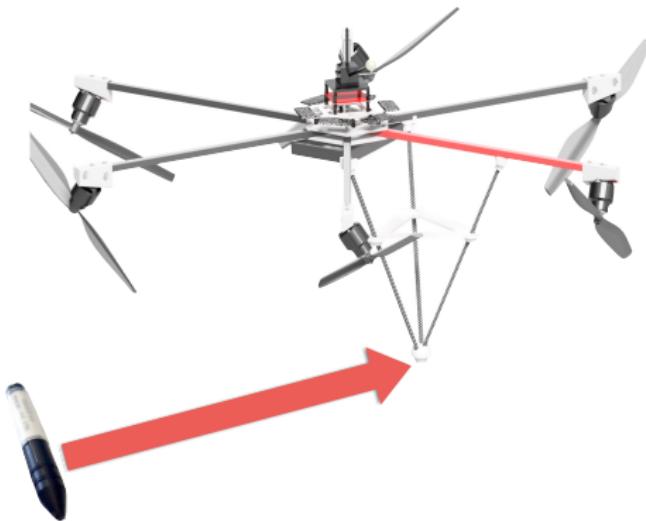
Platforms with **generic** rotor configuration:



[Rajappa, Ryll, Bültlhoff,  
**Franchi**, ICRA 2015]

Several total thrust directions become possible

## 6-DoF Flying End-Effector



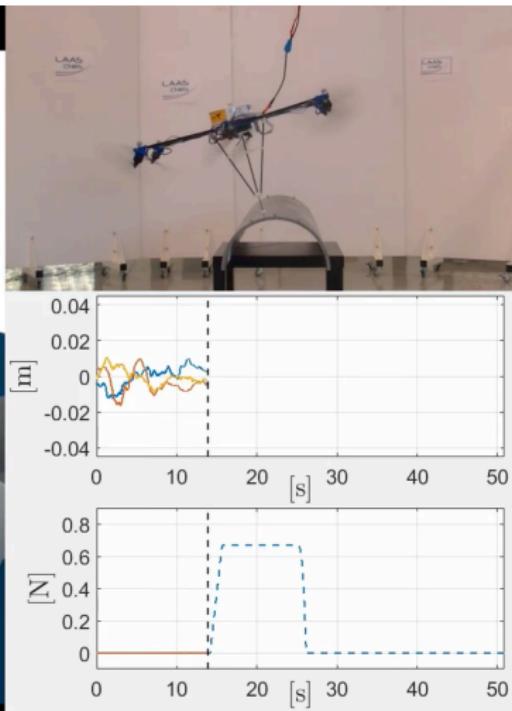
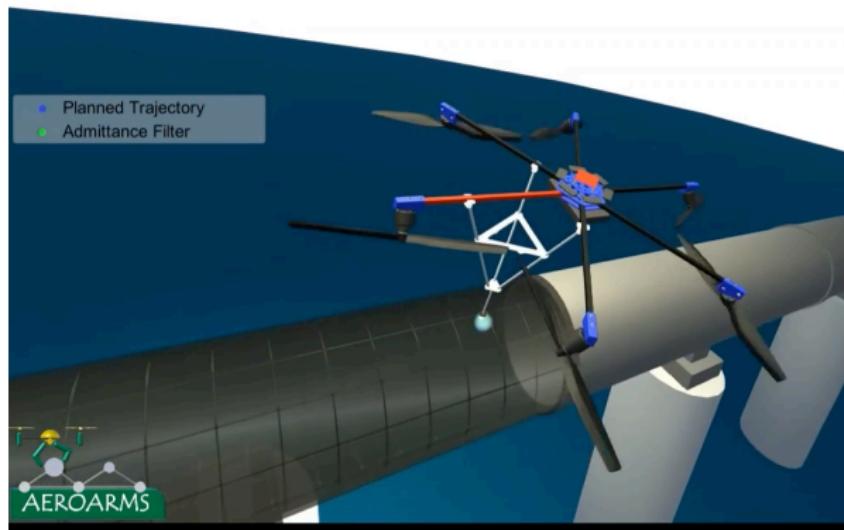
single rigid  
body

⇒ lighter  
⇒ mechanically simpler  
⇒ cheaper

than a  
manipulator

# Tilt-Hex by LAAS-CNRS (con't)

[Ryll, Muscio, Pierri, Cataldi, Antonelli, Caccavale, **Franchi**, ICRA 2017]



Path following + Pushing with given force

# Interaction with Over-actuation

fully  
actuated  
hexarotor



lightweight  
robotic  
arm

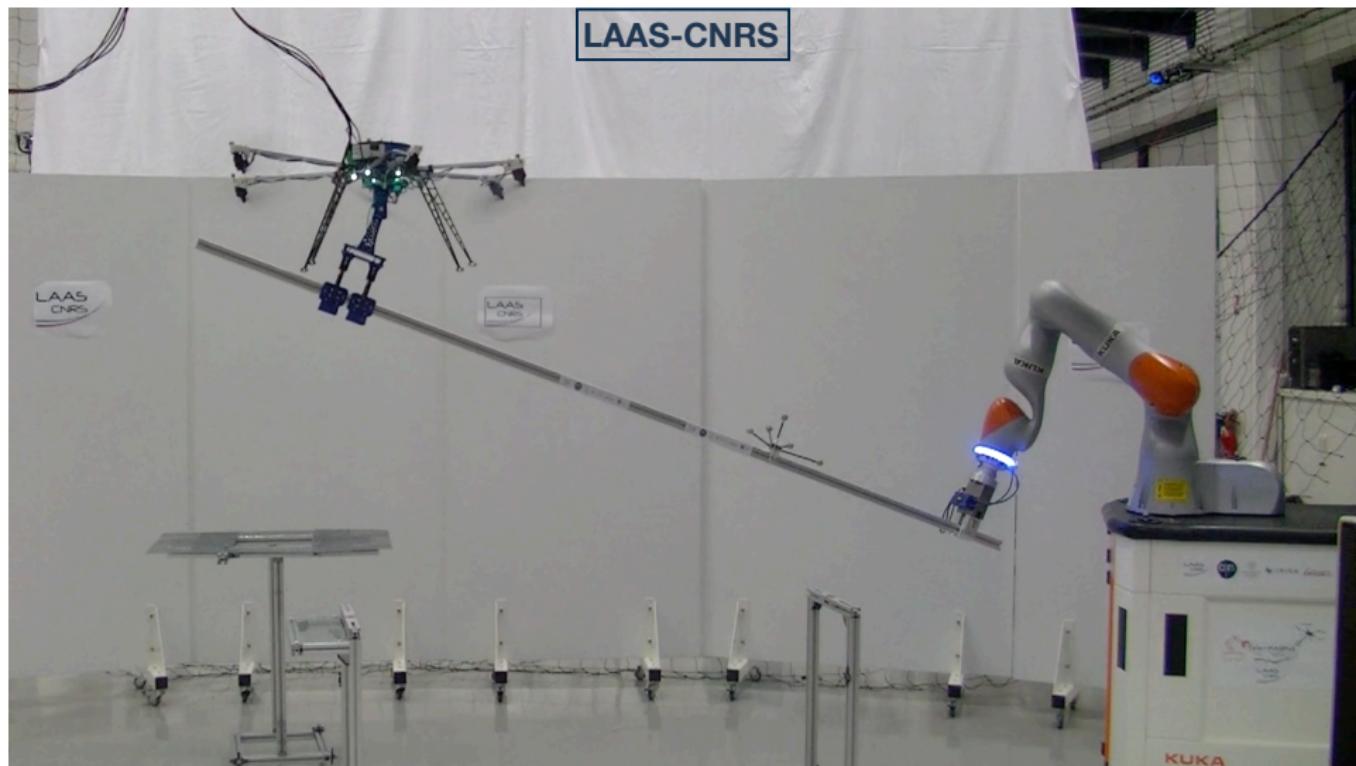
inspection  
proximity  
sensors



plant  
pipe

# Cooperative Manipulation

LAAS-CNRS



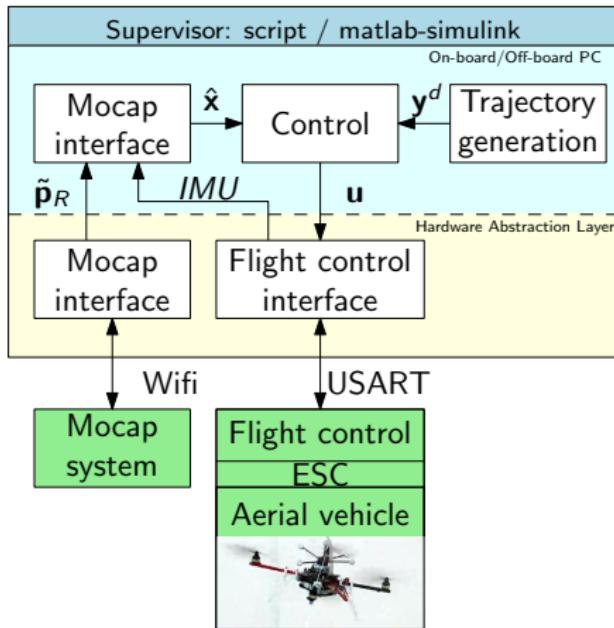
[Staub & al., subm. RAM 2017]

# Hardware/software setup

- Software
  - on-board C/C++ code using **genom**
  - middleware: **pocolibs**
  - possibility to use **off-board Simulink**

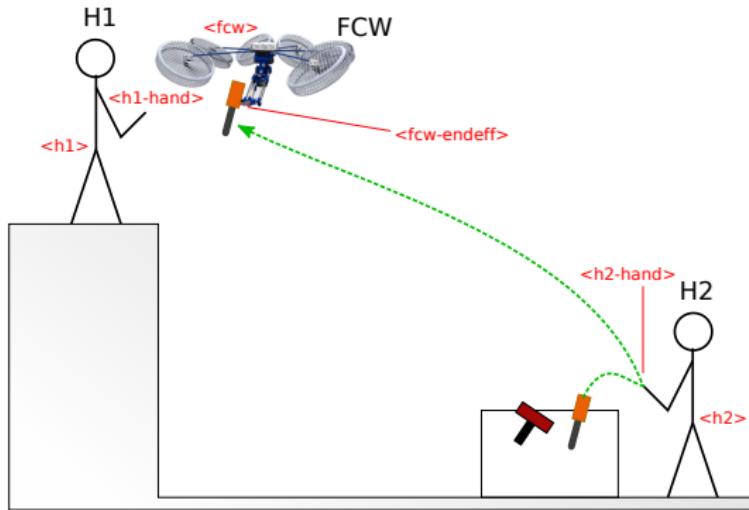
- on-board C/C++ code using **genom**
- middleware: **pocolibs**
- possibility to use **off-board Simulink**

- Hardware
  - aerial vehicles
  - mocap system



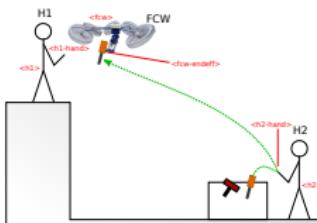
# The flying coworker (FCW) - ANR project

# The flying coworker (FCW) - ANR project



- A FCW capable of manipulation abilities that physically cooperates with a worker
- Combine HRI and Aerial Manipulation
- Partners: LAAS-CNRS and INRIA Nancy
- 2018-2022 ANR project

# The flying coworker



- Cooperate in a safe, effective, acceptable, and fluent manner.
- FCW combines
  - agility and large workspace of a flying robot
  - perception, decisional, and interaction skills of a collaborating robot
- Constraints

## The flying coworker

- Hexa-rotor with an arm, fan guards, sensors



- The dynamic model cannot be neglected
- Velocity inputs are not sufficient for control
  - Accelerations and forces must be planned and controlled
- FCW cannot be still when physically interacting, especially with human
- Cannot be precise, because of disturbances

# The flying coworker

- Planning motions for interactions must take into account the constraints of the platform.
- Human can put the robot and himself in danger
  - Because the propeller forces are limited, the platform is poorly balanced in some attitudes
- FCW can't stop in the air
  - plan and control a landing procedure
  - the human should be made aware of this procedure



# Control of the flying coworker

- Reactive control is generally not a good idea
- Continuously plan and control a trajectory in a receding-horizon (predictive model)



- Physical human-robot interaction for a FCW
  - Hardware and low level control
- Perception and interpretation of human activity
- Human-aware motion planning and control for FCW
- Task planning and collaborative task achievement
- Integration and demonstration
  - Manipulation of a long bar
  - Collaborative work

# Thanks – Questions?