Aerial Manipulation

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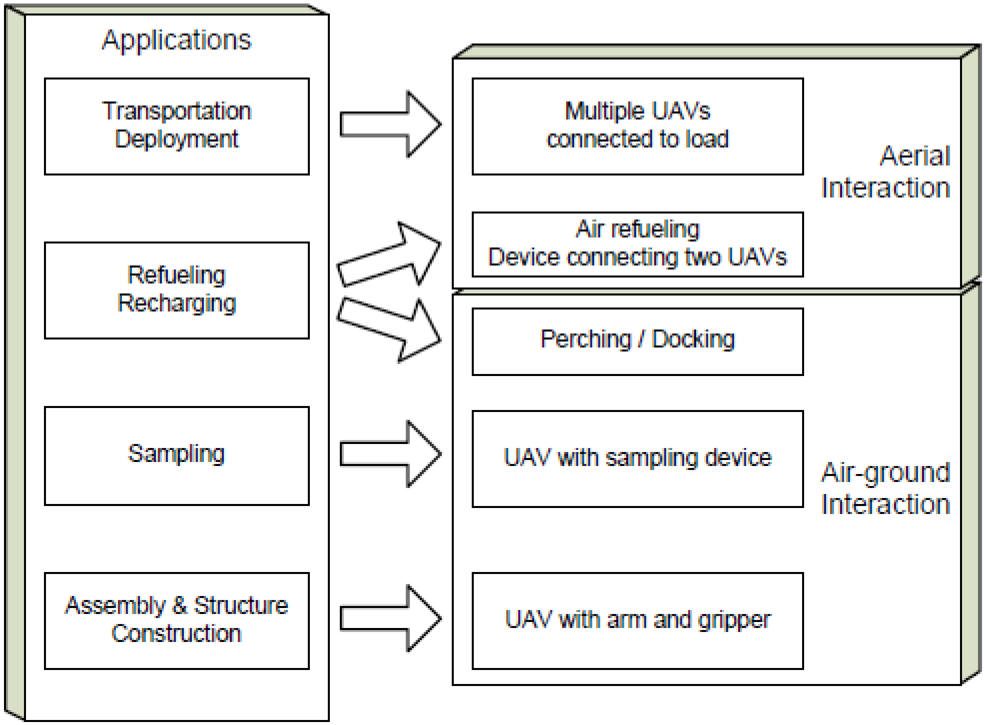
Outline

- Introduction
- Load transportation
- Aerial robotic manipulation
- Evolution of aerial robotic manipulators
- Methods and tools for aerial robotic manipulation. What is achievable?
- Conclusions

Physical interactions of aerial robots



Unmanned Aerial Systems Physically Interacting with the Environment. Load Transportation, Deployment and Aerial Manipulation", K. Kondak, A. Ollero, I. Maza, K. Krieger, A. Albu-Schaeffer, M. Schwarzbach and M. Laiacker. Handbook of Unmanned Aerial Systems. Springer. 2014.

Load transportation

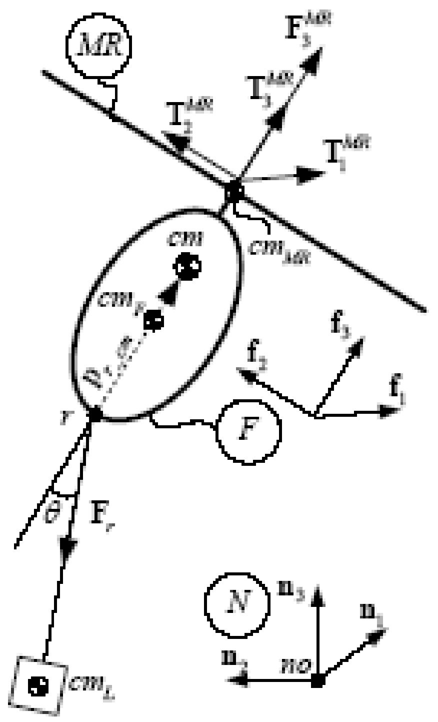
- Future cargo transportation without pilots

- Today is a popular application for multi-rotor systems
  - Constraints:
    - Payload
    - Flight endurance
    - Regulations

- Slung load transportation
  - Helicopter application
  - Joint load transportation



Joint load transportation: The AWARE FP6 project (2006-2009)

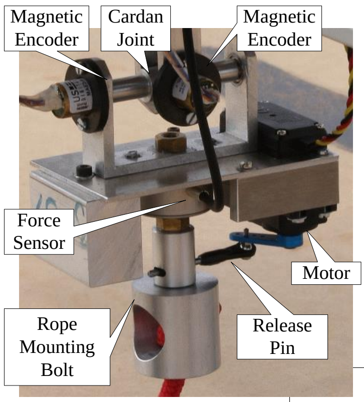


The rope force $\mathbf{F_r}$ causes a non-zero torque $\mathbf{T_r} = \mathbf{F_r} \times \mathbf{p_{r\text{-}cm}}$ on the helicopter fuselage

$\mathbf{T_r}$ depends on orientation of the helicopter and its translational motion in the frame *N*

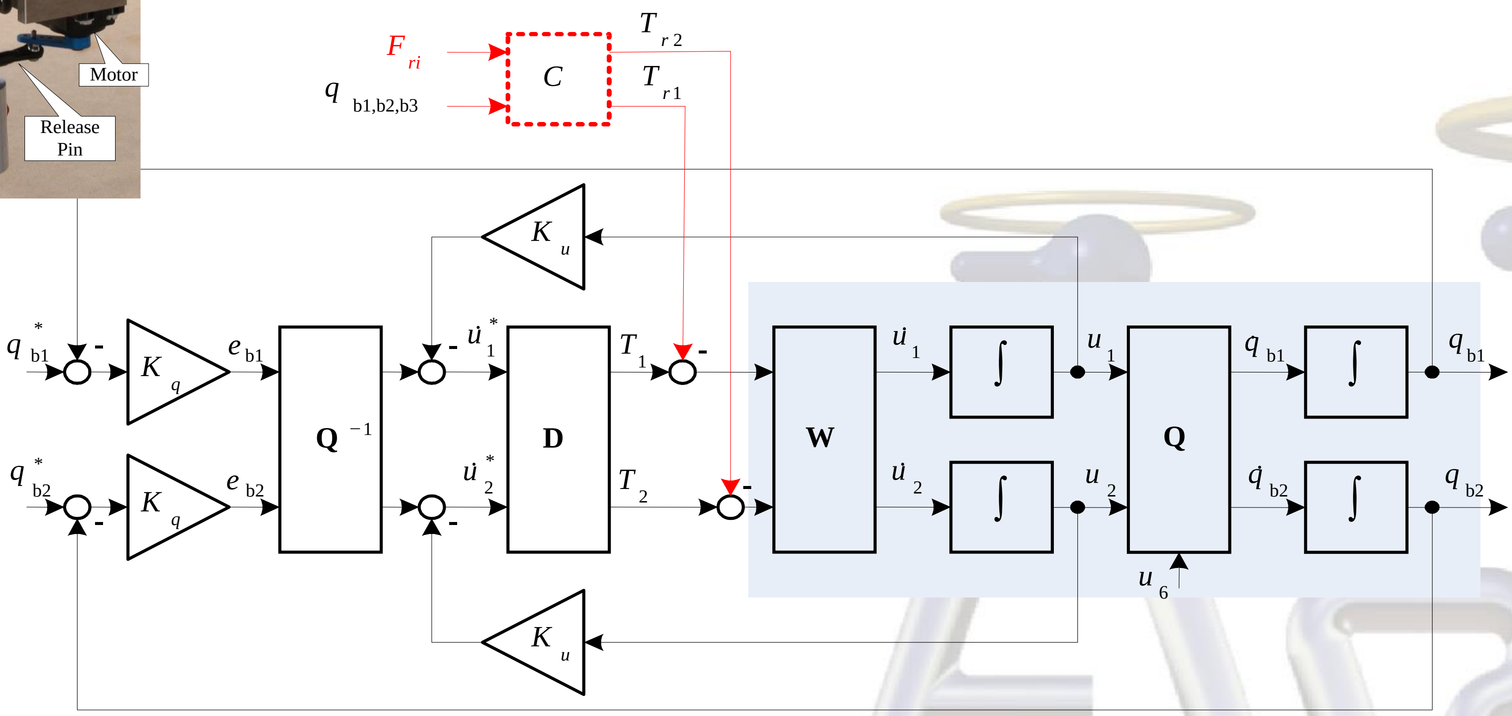
Several helicopters connected to the load: translational and rotational motion of one particular helicopter has direct influence on the rotation dynamics of all other helicopters

Even the translation with constant acceleration, can cause oscillation of the angle θ between the rope and the helicopter axis.



Joint load transportation: The AWARE FP6 project (2006-2009)

Orientation controller with feedforward

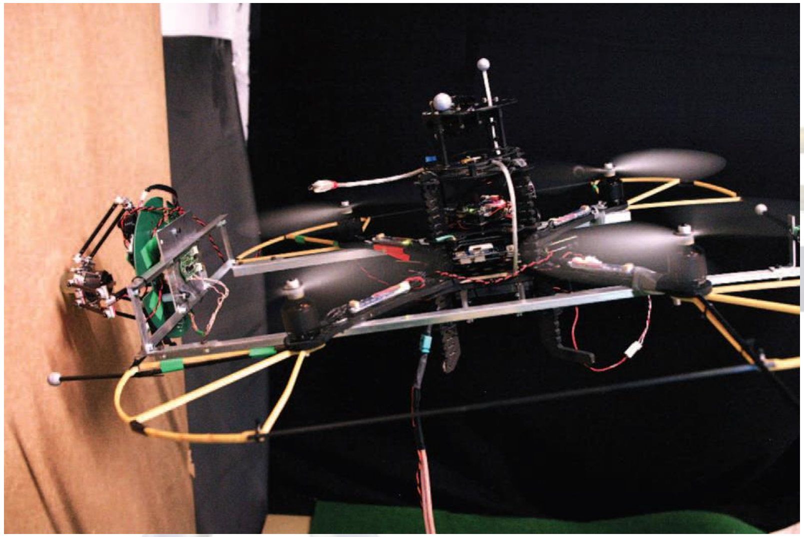


- Usage of the rope force F_{ri} for decoupling.
- The orientation controller becames independent of number of helicopters

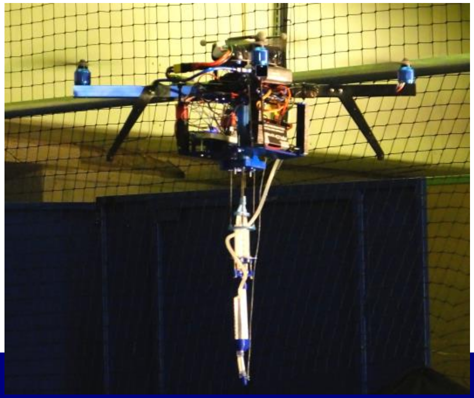
Joint load transportation: The AWARE FP6 project (2006-2009)

AWARE FP6 project 2006-2009

Aerial grasping, Yale University, 2011

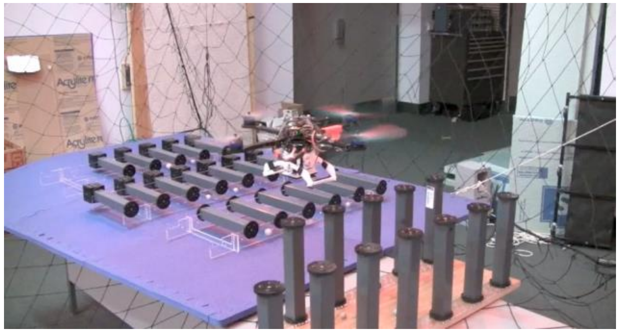


Maintain contact and pushing, FP7 AIRobots project (2011-2014). University of Twente



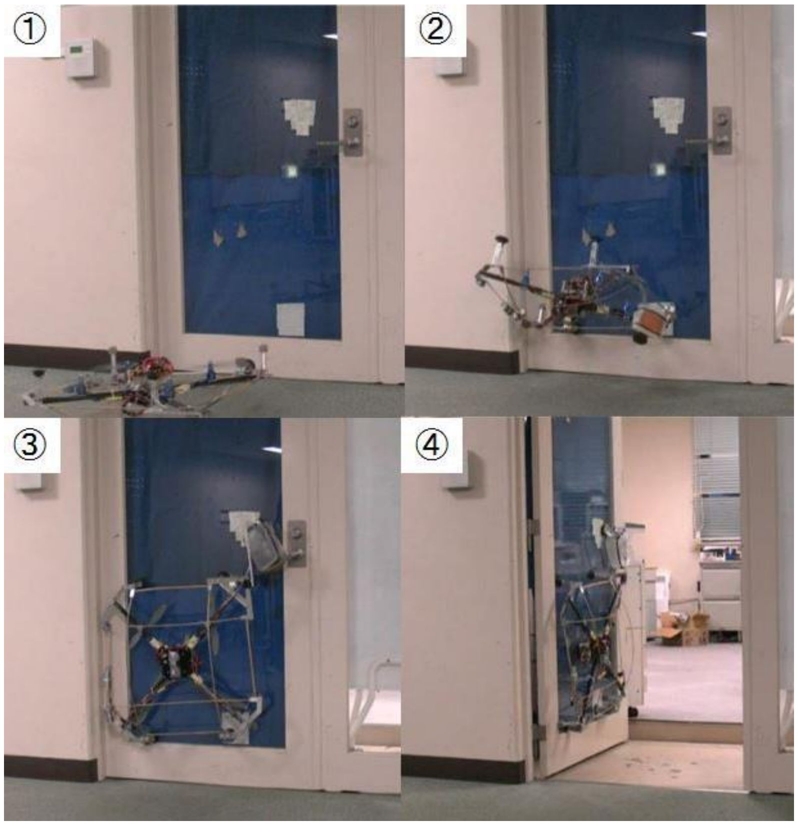
3D Printing, Imperial College, 2014

University of Pensylvania,

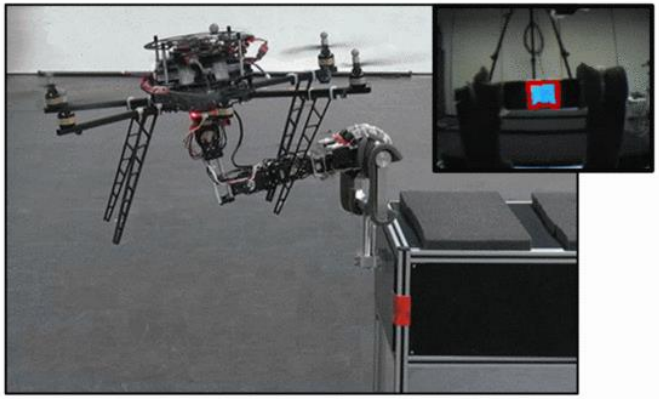


Structure construction, 2011

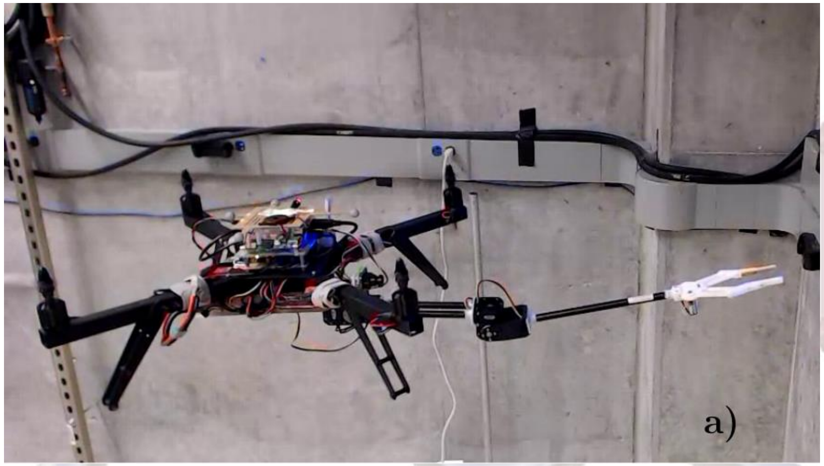
Avian Inspired Grasping, 2013



Opening a door, Tokyo Institute of Technology, 2015



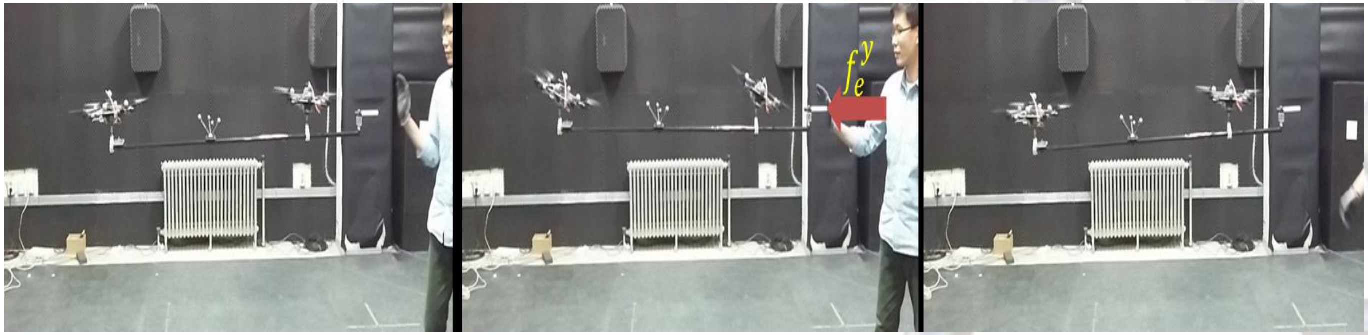
Operating an Unknown Drawer, Seoul,National University, 2015



Johns Hopkins University, 2015

Parallel Manipulator, University of Nevada, 2015

Manipulation with two hands, University of Zagreb, 2014

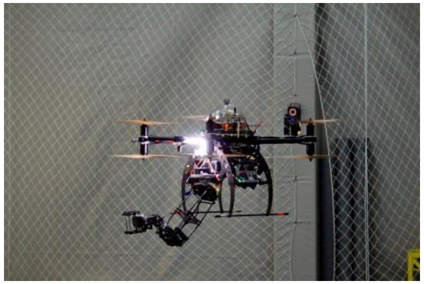


Cooperative bar transportation, Seoul National University, 2015

Aerial robotic manipulation

FP7 ARCAS, CATEC 2012

FP7 ARCAS, DLR 2012



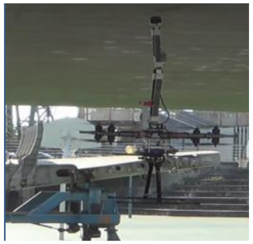
FP7 ARCAS, CATEC 2014

FP7 ARCAS, Univ. Sevilla 2014

FP7 ARCAS, DLR, 2015

FP7 ARCAS, CATEC, 2015

H2020 AEROARMS, Univ. Sevilla 2016



H2020 AEROBI, Univ. Sevilla 2016

Initial questions (2010)

- What kind of aerial platform do we need?
  - Configurations
    - Helicopters
    - Multi-rotor systems
  - Payload
- Do we need robotic arms or simply gripping mechanisms ?
- How many degrees of freedom in the arm do we need ?
- What kind of perception and planning functionalities do we need?
- What kind of cooperation do we need ?

Answers

- What kind of aerial platform do we need?
  - Configurations
    - Helicopters

      More payload, better manipulation capabilities, outdoor
    - Multi-rotor systems:

      Mechanical simplicity, constrained space, low payload, simpler arms, indoor and outdoor
  - Payload:

    Tens of Kilograms for helicopters

    Hundreds of grams or few Kilograms for multi-rotor systems
- Do we need robotic arms or simply gripping mechanisms ?

  Many applications require robotic arms
- How many degrees of freedom in the arm do we need ?

  Increasing the number provide accomodation and dexterity

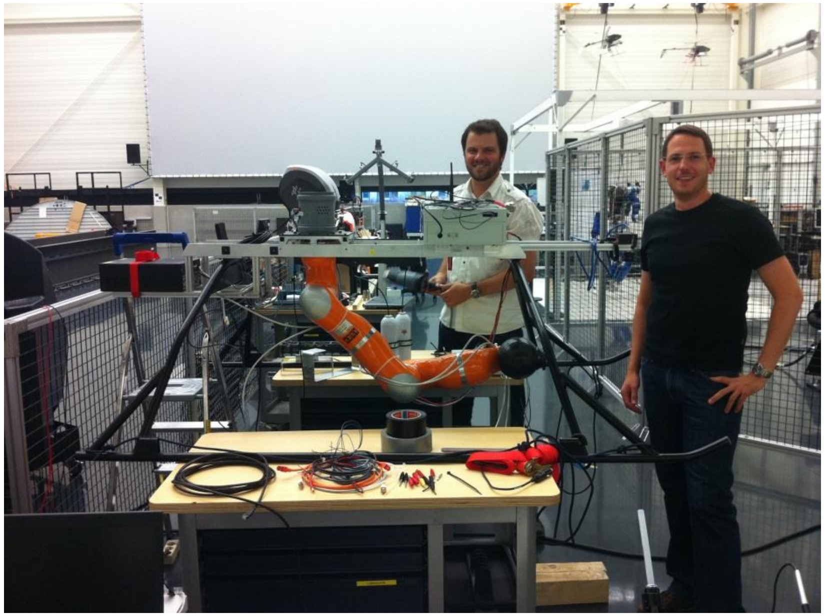
Answers

- What kind of perception and planning functionalities do we need?
  Perception:
    Low level vision, object detection and recognition, Fast 3D modelling, Tracking of 3D objects
    Vision and range sensors using radio systems and time of flight
  Planning:
    Assembly planning, task allocation, motion planning, collision detection and avoidance
- What kind of cooperation do we need?
    Cooperative perception, cooperative bar transportation

General conclusion:

General dexterous manipulation capabilities, perception and planning capabilities

Evolution of outdoor helicopter platform in the ARCAS Project

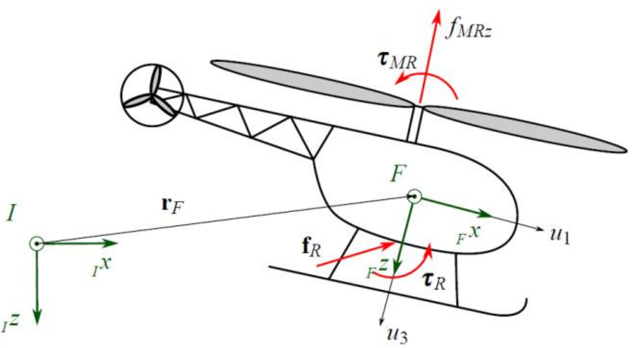


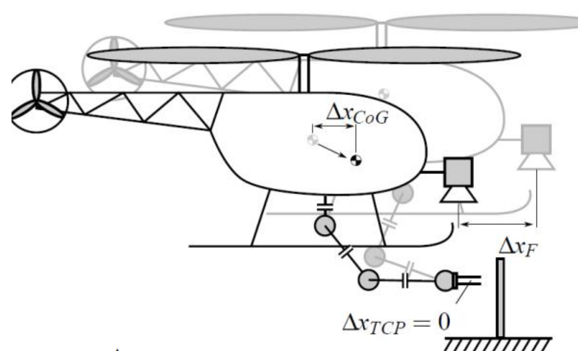
Integration at DLR, 2012

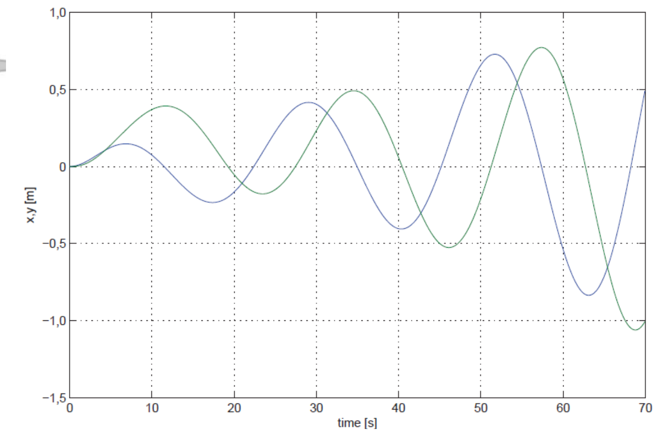
- First experiments with advanced manipulator, 120 kg take off weight
- Mechanical integration ?
- General flight capabilities of helicopter ?
- Feasible in the scope of ARCAS project ?

Conventional helicopters

When manipulator compensates a displacement of helicopter, low frequency oscillations with increasing amplitude could appear

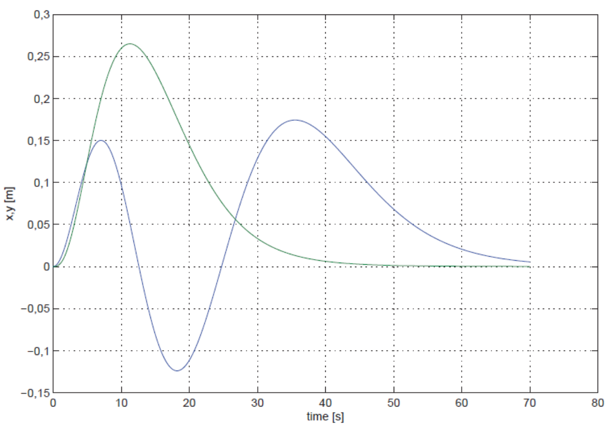


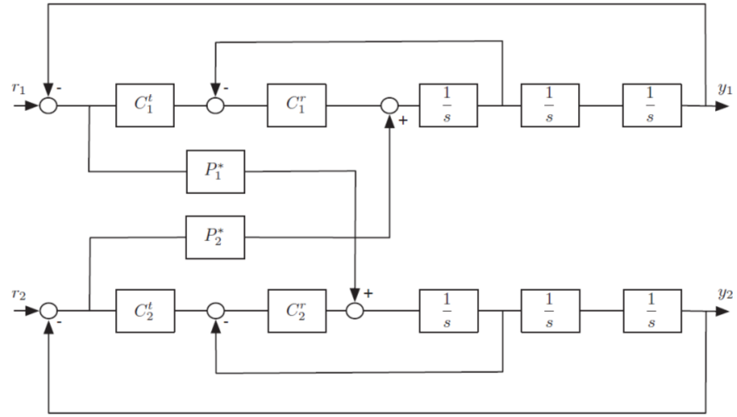




$$\Delta x_F \rightarrow \Delta x_{CoG} \rightarrow \tau_{R2} \rightarrow u_4 \rightarrow u_2 \rightarrow \Delta y_F \rightarrow \Delta y_{CoG} \rightarrow \ldots.$$

A kinematic coupled arm controller can reduce oscillations





$$G_{11} = \frac{C^r C^t s^3 + (C^r)^2 C^t s^2 + (C^r C^t)^2 - P_1^* P_2^*}{s^6 + 2C^r s^5 + (C^r) s^4 + 2(C^r C^t)^2 s^3 + 2(C^r)^2 C^t s^2 + (C^r C^t)^2 - P_1^* P_2^*}$$

Outdoor platforms development summary

Integration at Universidad de Sevilla

V0.0

V1.0

V2.0

V0.0

V1.0 & V1.1

Integration at DLR

V2.0 & V2.1

- changes and adaptation in mechanics, electronics and software architecture
- reduction of weight and size
- increase of power
- increase of endurance
- connection to the leading edge manipulation

Evolution of aerial robotic manipulators

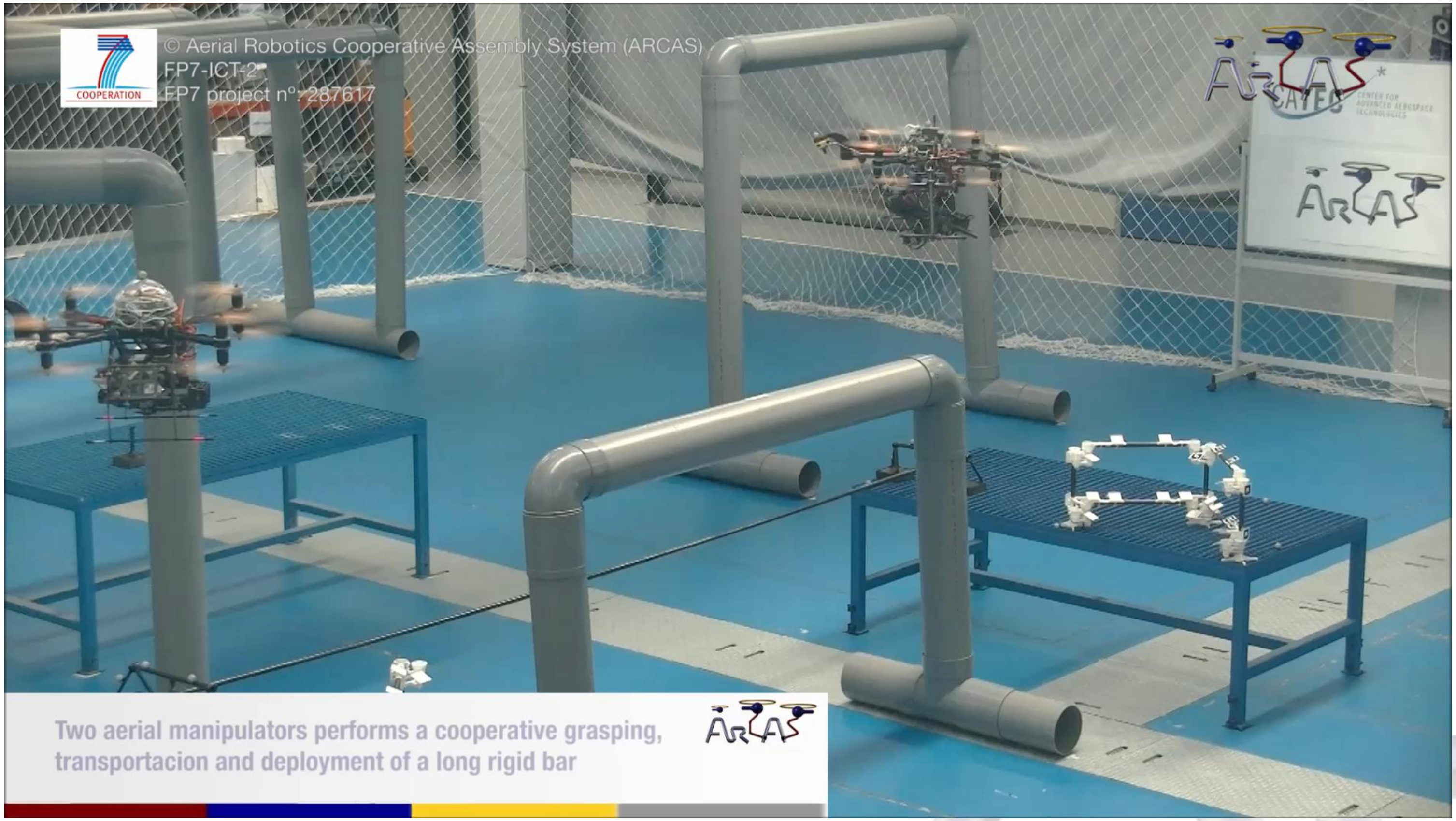
Indoor platforms development summary

Integration at CATEC

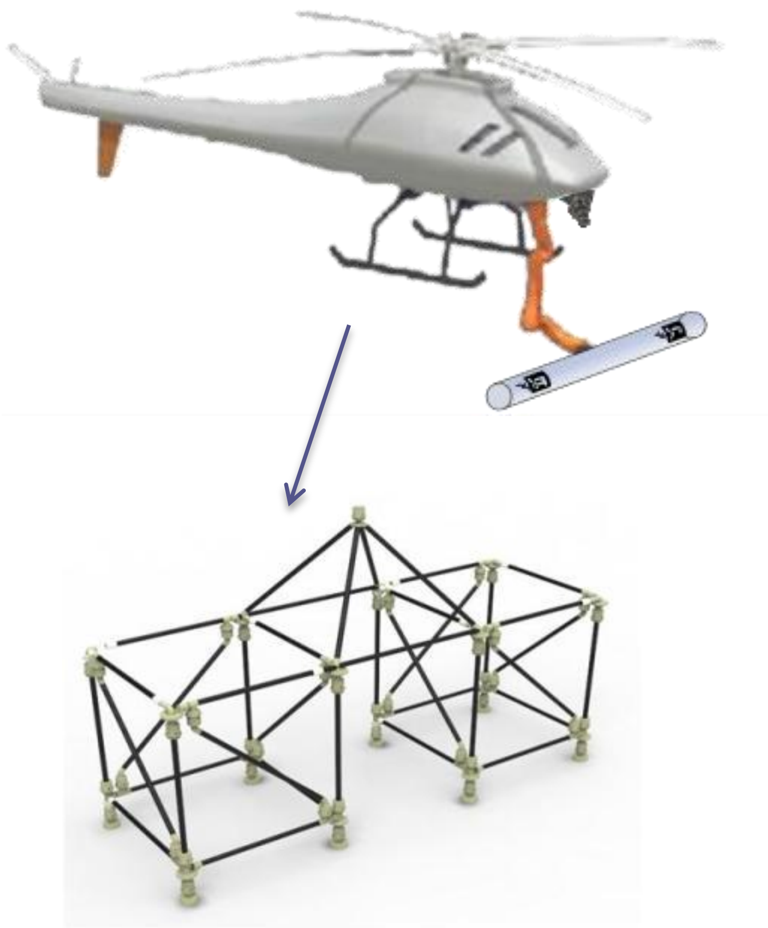
- Increase payload and robustness
- Improvements in mechanics and electronics

- Stability problems in the aerial platform due to the motion of the arm
- Dynamic effects in the manipulator due to the motion of the floating platform
- Control approaches
  - Two separate entities: effects considered as dynamic disturbances
  - Two separate entities with motion aware control: control of an entity with motion information of the second entity
  - Aerial platform and manipulator as single entity, and thus the controller is designed on the basis of such complete dynamic model

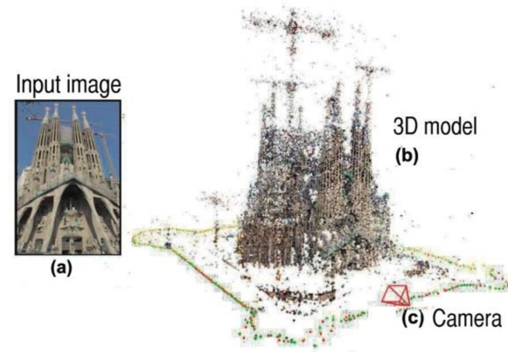
Methods and tools for aerial robotic manipulation. What is achievable? Control



Localization



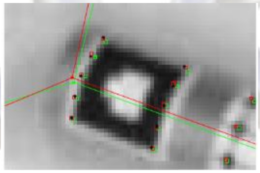
Appearance-based
Robot localization
< 1 m accuracy



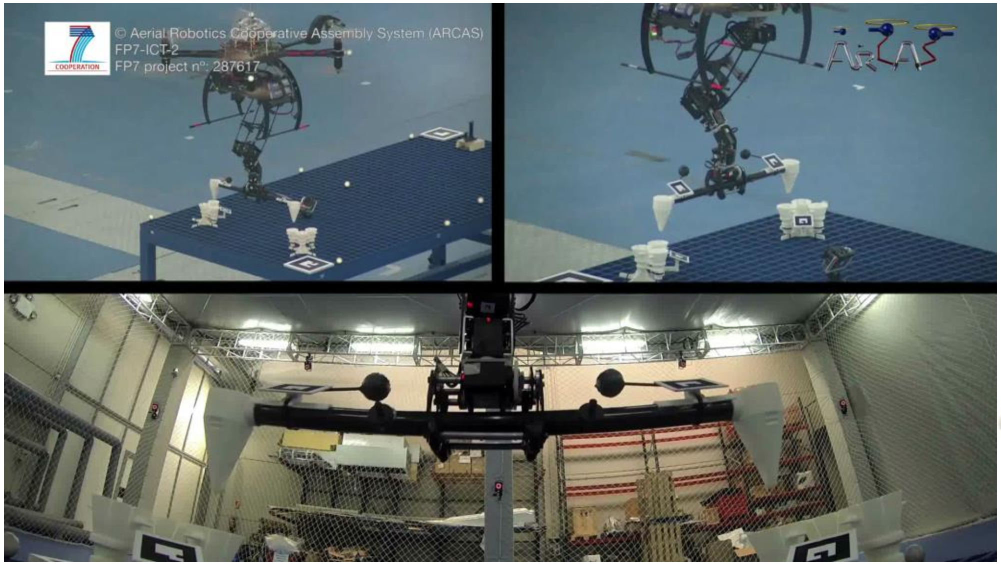
Range Only SLAM
localization
< 0,7 m accuracy

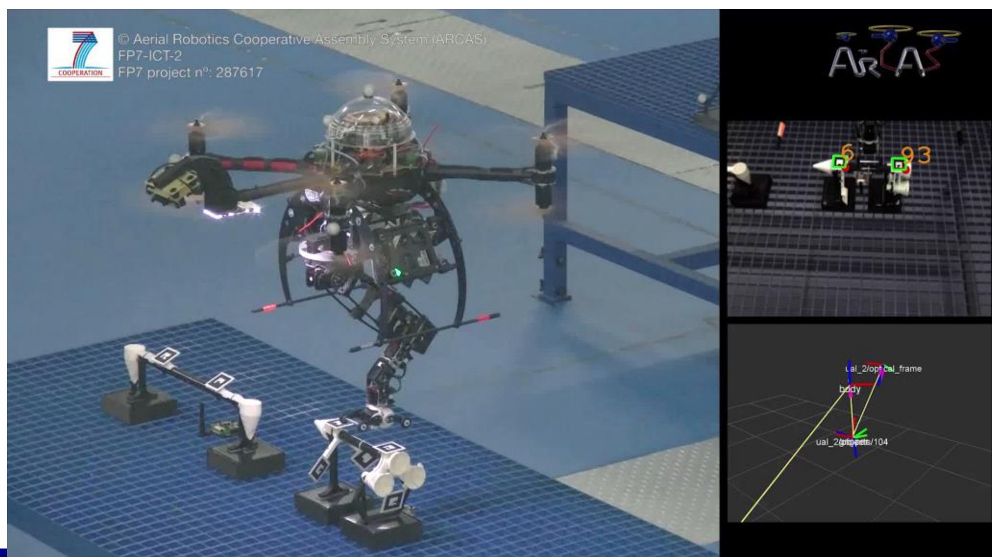
Marker-based
Robot localization
2 to 4 cm accuracy

Marker-based
3D pose estimation
for task execution
0,75 to 1,25 cm accuracy



ARCAS



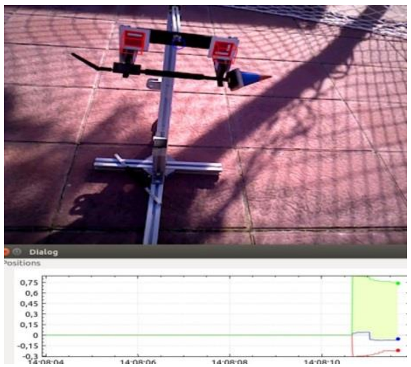
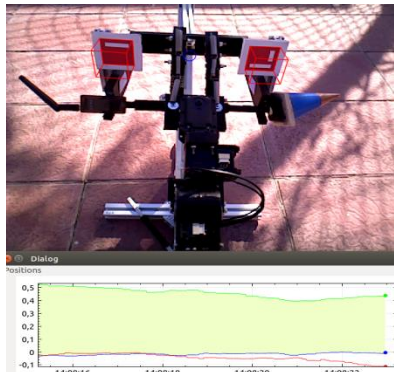
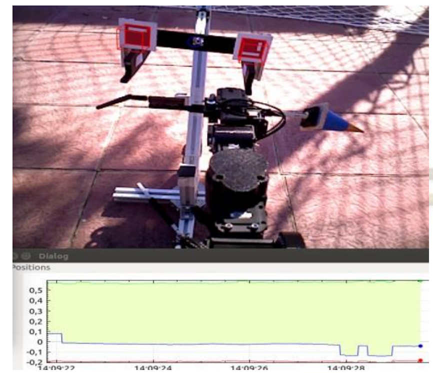
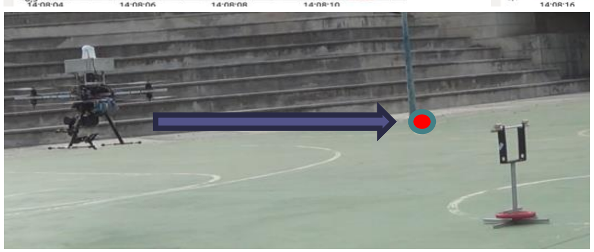
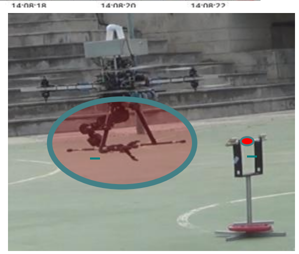
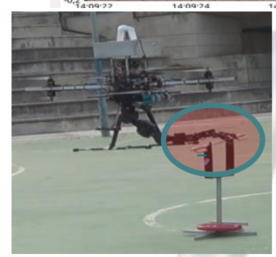
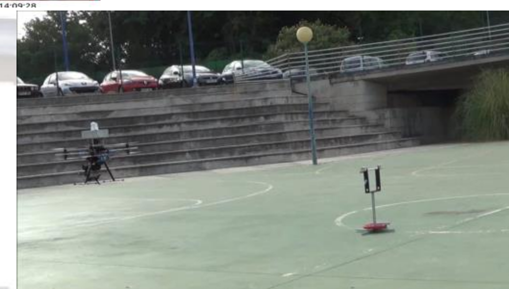
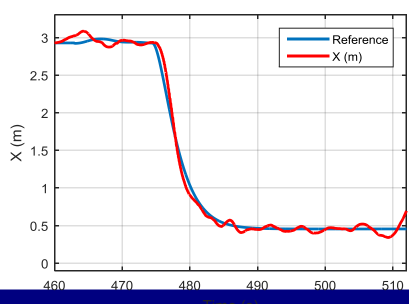


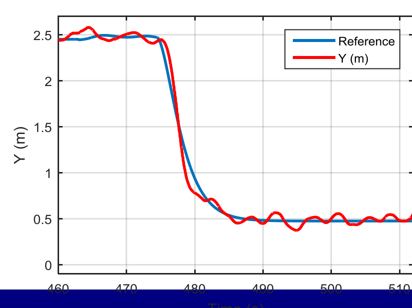
Hybrid visual servoing with hierarchical task composition: subtasks in the cartesian space, in the image space, and in the joint space

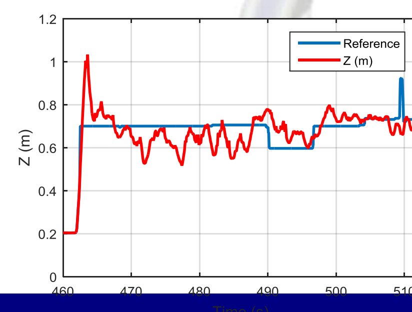
Mutirotor outdoor navigation and grasping experiments

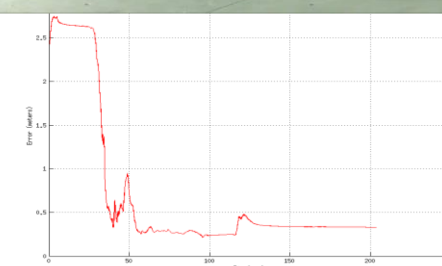
Range-Only localisation (bar with range sensor and anchors) and Differential GPS

Visual perception: Marker detection distance (0,1 to 0,96m), Adaptive brightness, Stabilization based on optical flow and a Kalman filter, can work with only one tag







Methods and tools for aerial robotic manipulation. What is achievable? Planning

	Scenario/ Conditions	ARCAS Fulfillments
Assembly planning (Univ. Sevilla)	Structure with ~40 bars	CPU time ≈ 1s Using physics engine
Task planning (LAAS-CNRS)	3 UAVs, 13 bars, various constraints	CPU time < 1min
Local motion planning (LAAS-CNRS)	1 UAV (no arm motion)	1000 times faster than optimal control 5% sub-optimal (average)
Global motion planning (LAAS-CNRS)	1 UAV, complex industrial scenario	CPU time < 3s to find a first solution (up to 50% sub-optimal)
Complete planning module (LAAS-CNRS)	2 UAV (1 manipulator, 1 with camera), ~10 bars	CPU time < 2min to obtain a geometrically feasible plan
Multi-UAV reactive collision avoidance (Univ. Sevilla)	10 UAVs in the indoor scenario	CPU time = 1ms Guaranteed safety

•FP7 ARCAS (http://www.arcas-project.eu) Sharable Products

Shareable Product	Type	Exploitation	Owners
Datasets for Range-Only (RO) SLAM using aerial vehicles	Dataset	Create an aerial RO-SLAM web page linked to the ARCAS Website with all datasets and explanations: http://grvc.us.es/staff/caba/roslam	USE
Open RO-SLAM source code as a ROS package	Source Code	Debug and clean source code Upload to ROS Website: http://wiki.ros.org/nanotron_swarm Upload to the aerial RO-SLAM Web page linked to ARCAS Website	USE
Datasets for detection of natural landmarks	Dataset	Create a web page linked to the ARCAS Website with the dataset and explanations: http://www.iri.upc.edu/people/mvillami/files/iri_natural_targets_dataset_v1.1.zip	UPC
Simulink diagrams for cooperative control	Source Code	Create a web page linked to the ARCAS Website with the Simulink diagrams and explanations http://www2.unibas.it/automatica/multimedia.html	UNINA-UNIBAS
Structure Assembly Sequence Planner Tools	Source Code	Published at https://github.com/technik/assemblyTool	USE
Symbolic task planner for robotics	Source Code	Published at openrobots.org Create a web page linked to the ARCAS Website with the source code and explanations: https://www.openrobots.org/wiki/HATP	LAAS-CNRS
Motion planner for aerial robots	Source Code	Publish at openrobots.org Create a web page linked to the ARCAS Website with the source code and explanations: https://www.openrobots.org/wiki/move3d	LAAS-CNRS

Conclusions

- Load transportation and aerial manipulation are feasible
- Aerial manipulation is not only installing a robotic arm on a drone
- Depend on relative sizing (i.e. relative weight, reach, manipulation constraints)
- Good and fast controllers needed
- Embedded perception functionalities
- Reactivity needed
- Planning with good models

Please visit the sites

http://www.arcas-project.eu/

http://www.aeroarms-project.eu/

for more information