

From **Filippo's car** to **Antonio's drones**

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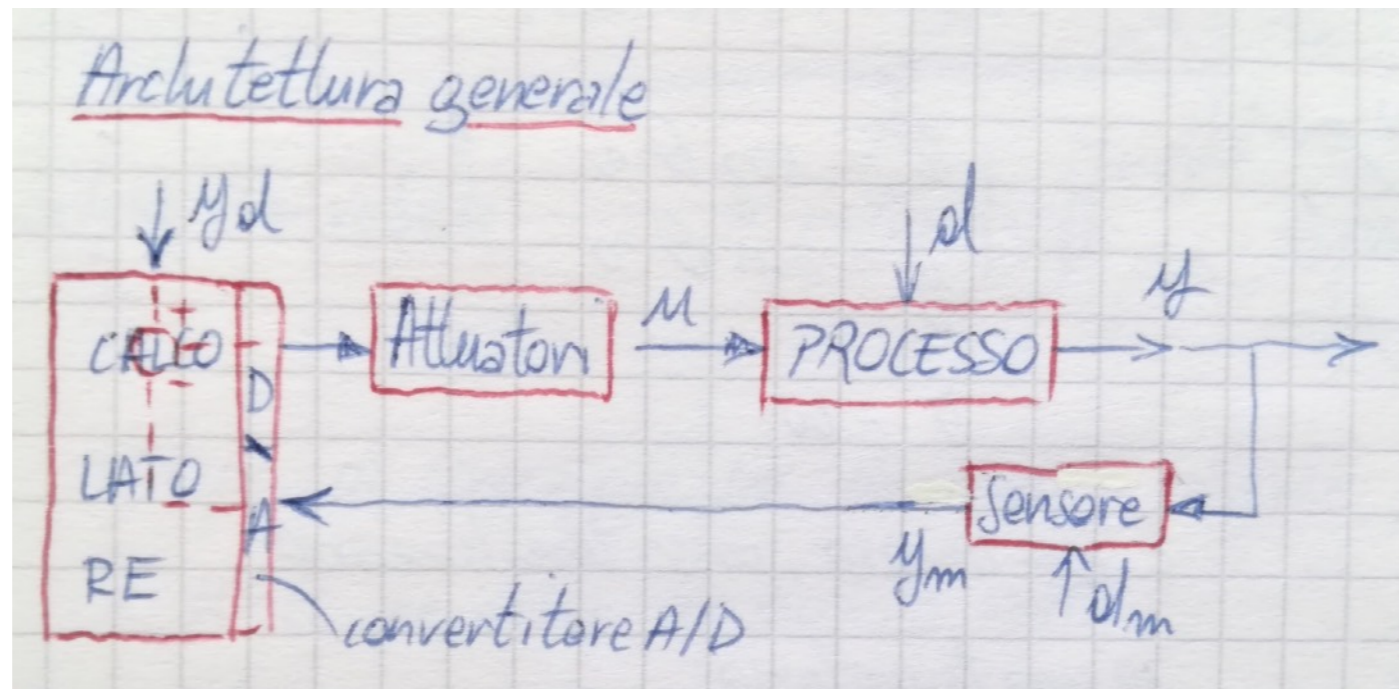
A workshop in honor of Alessandro De Luca
for his 60th birthday

Sapienza University, Rome, January 9th, 2018

Alessandro's Inception



Automatic Control Class (2002)



(probably) the first feedback block diagram I wrote

Alessandro's Inception (con't)



Robotics Class (2003)

$$\sum_j b_{kj}(q) \ddot{q}_j + \sum_{i,j} \left(\frac{\partial b_{kj}}{\partial q_i} - \frac{1}{2} \frac{\partial b_{ij}}{\partial q_k} \right) \dot{q}_i \dot{q}_j + \frac{\partial U}{\partial q_k} = u_k \quad k=1, \dots, N$$

↓ simmetrizzando

$$\dots + \sum_{i,j} \frac{1}{2} \left(\frac{\partial b_{ki}}{\partial q_i} + \frac{\partial b_{ki}}{\partial q_j} - \frac{\partial b_{ij}}{\partial q_k} \right)$$

= c_{kij} simboli di Christoffel = c_{kji}

termini inerziali

termini centrifughi ($i=j$)
e di coriolis ($i \neq j$)

termini gravitazionali

matrici vettoriali

$$B(q) \ddot{q} + C(q, \dot{q}) + g(q) = u$$

elemento di C

$$c_k(q, \dot{q}) = \dot{q}^T C_k(q) \dot{q}$$

dove $C_k(q) = \frac{1}{2} \left(\frac{\partial b_{ki}}{\partial q_i} + \frac{\partial b_{ki}}{\partial q_j} \right) - \frac{\partial b_{ij}}{\partial q_k}$

my first derivation of the Lagrangian model

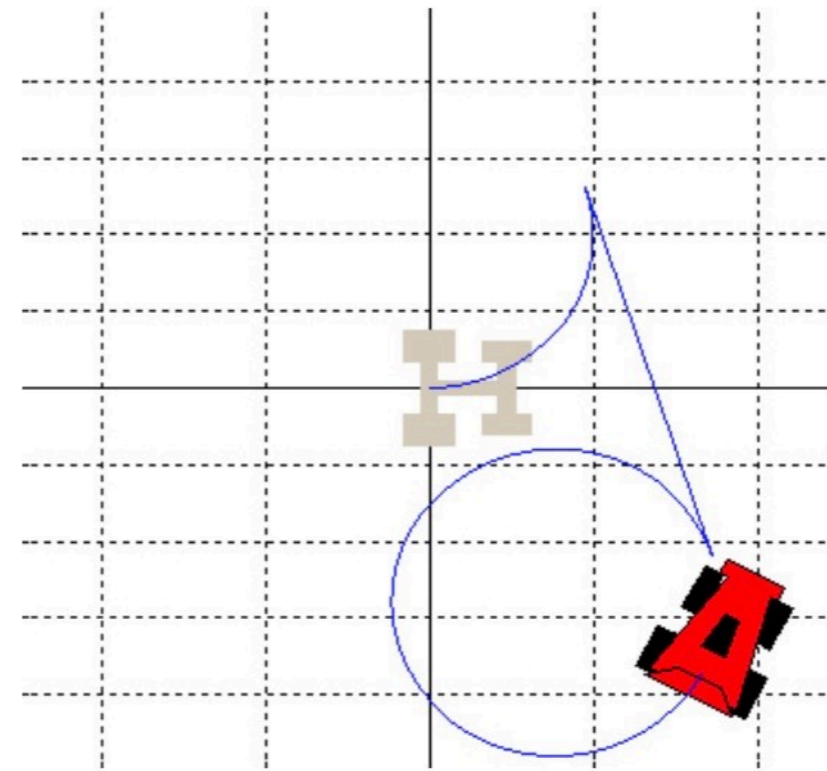
Alessandro's Inception (con't)

Robotics Class Project Motion Planning for the Filippo's Car

Università di Roma "la Sapienza"
Facoltà di Ingegneria

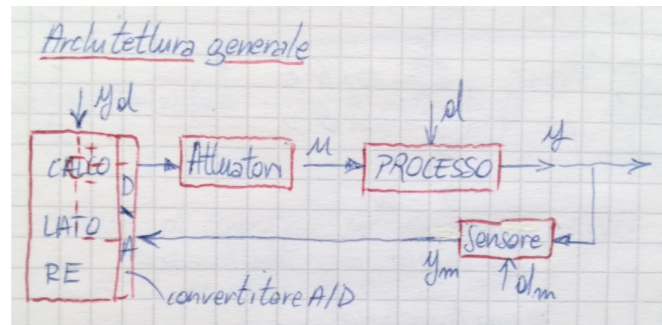
Corso di Robotica Industriale
Prof. Alessandro De Luca

PIANIFICAZIONE
DEL MOTO
PER LA
FILIPPO'S CAR



- Unicycle
- Only two constant inputs:
- Forward straight
 - Backward in circle

Alessandro's Inception (con't)



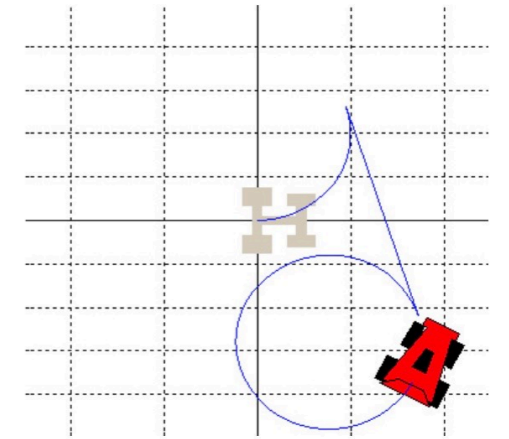
$$\sum_j b_{kj}(q) \ddot{q}_j + \sum_{i,j} \left(\frac{\partial b_{kj}}{\partial q_i} - \frac{1}{2} \frac{\partial b_{ij}}{\partial q_k} \right) \dot{q}_i \dot{q}_j + \frac{\partial U}{\partial q_k} = v_k$$

↓ simmetrizzando

$$\dots + \sum_{i,j} \frac{1}{2} \left(\frac{\partial b_{kj}}{\partial q_i} + \frac{\partial b_{ki}}{\partial q_j} - \frac{\partial b_{ij}}{\partial q_k} \right)$$

= c_{kij} simboli Christoffel = c_{kji}

termini inerziali termini centrifughi ($i=j$) e di Coriolis ($i \neq j$) termini gravità



Control

Robotics

nonconventional
'Challenges'



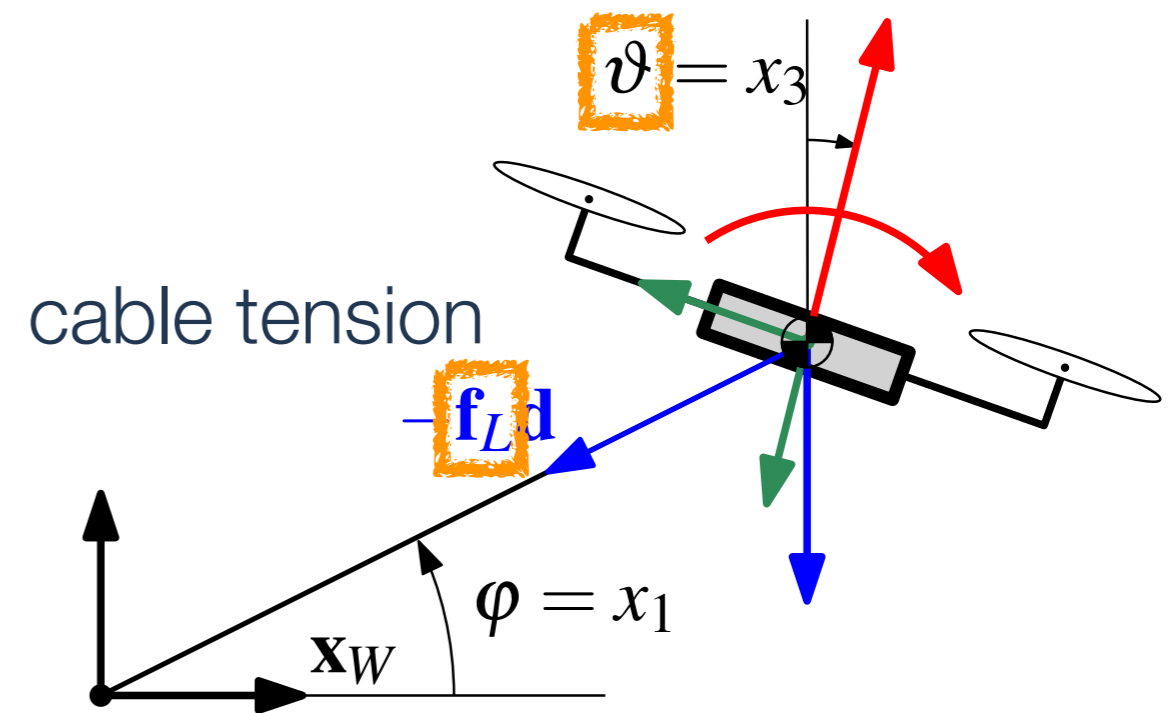
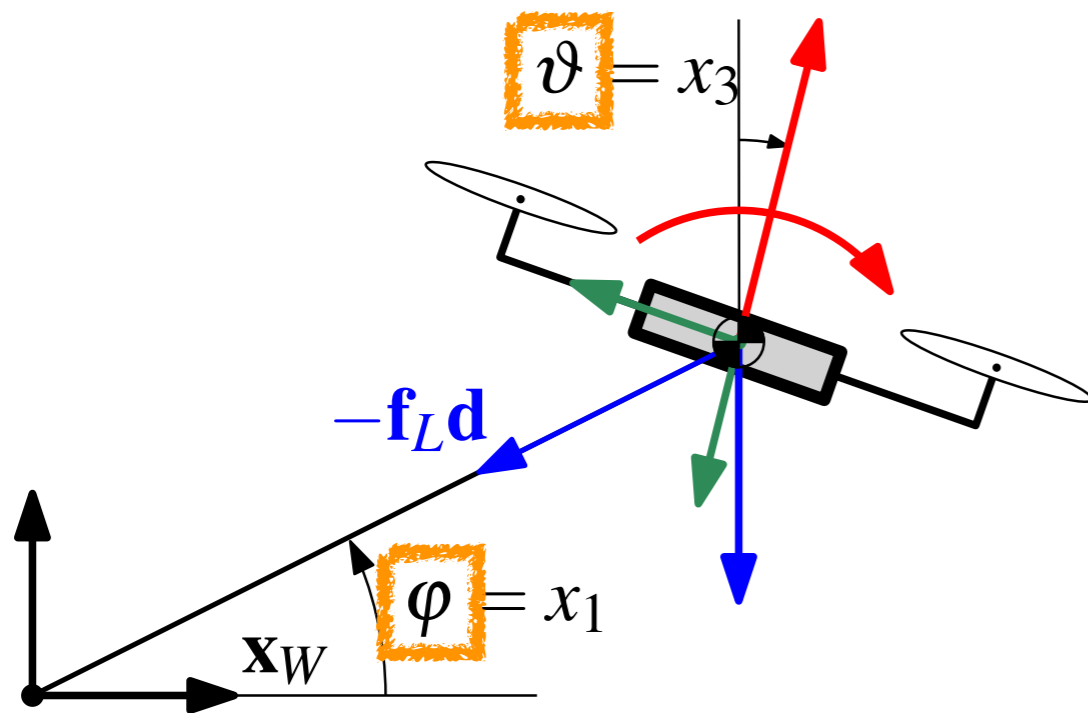
- 1) Solid **control perspective** to robotics
- 2) Interest in **nonconventional problems**

'Antonio's' Drones

- The **Spider-Rotor**
- The **Protocentric** Aerial Manipulator
- The **Tilt-Hex**
- The **Omni+7**

No time for:

- The **MAGMaS**
- The **Monkey-Rotor**
- ...



1) Two feedback linearizing (flat) **output pairs**

2) Full state observable using only gyroscope and accelerometer!

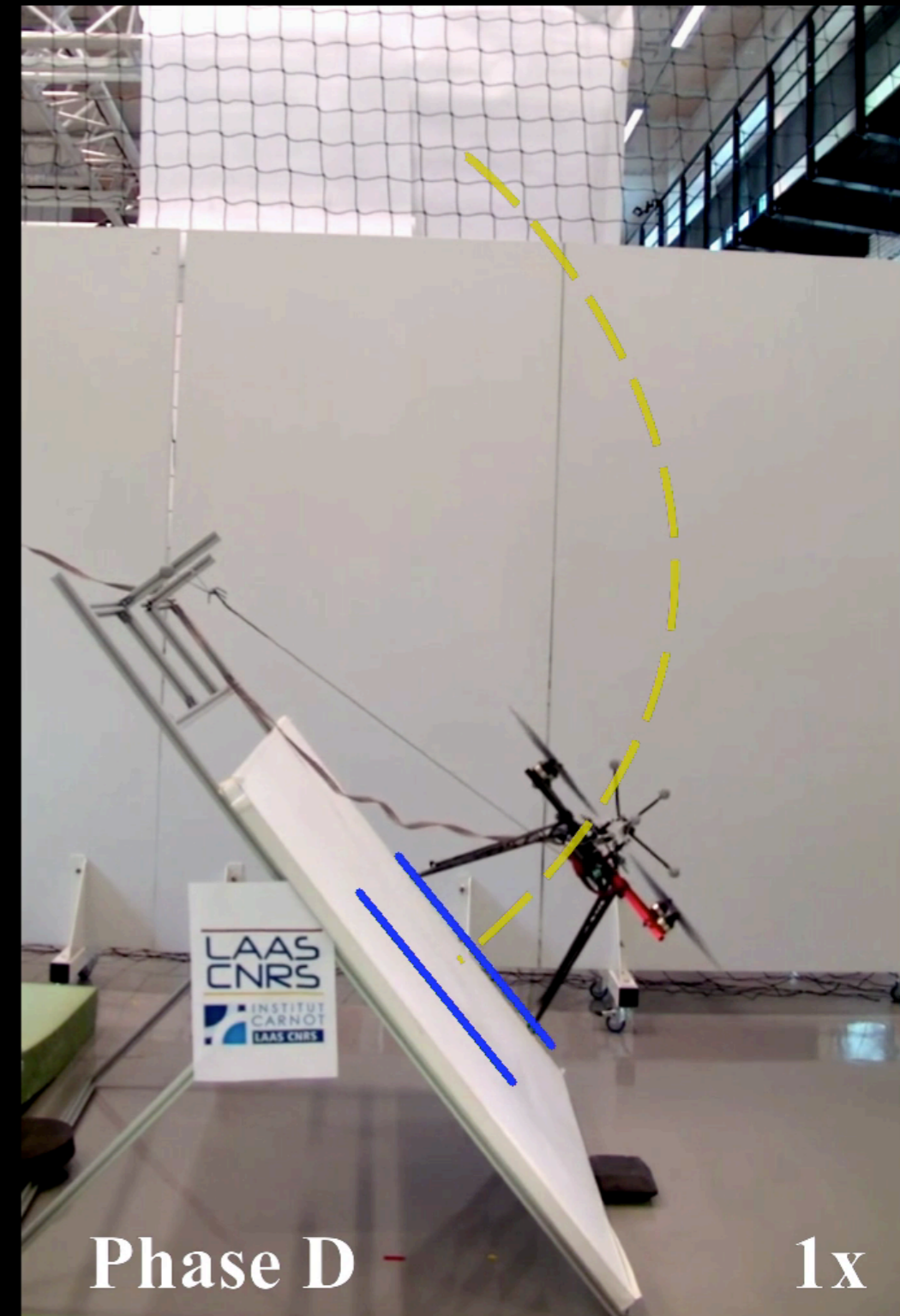
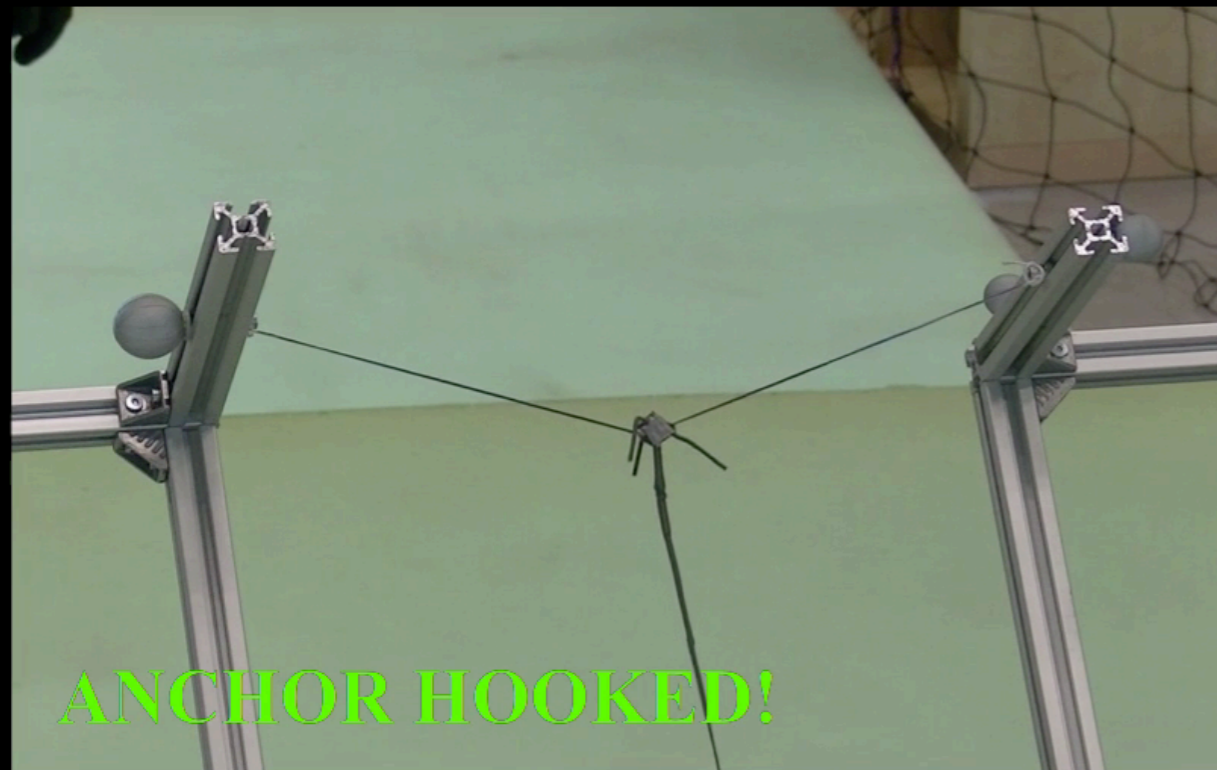
1) The Spider Rotor (con't)

Phase D: Landing

While the elevation is decreased:

- * the tether is kept taut
- * the pitch is steered to the surface angle exploiting the possibility of inclined hovering.

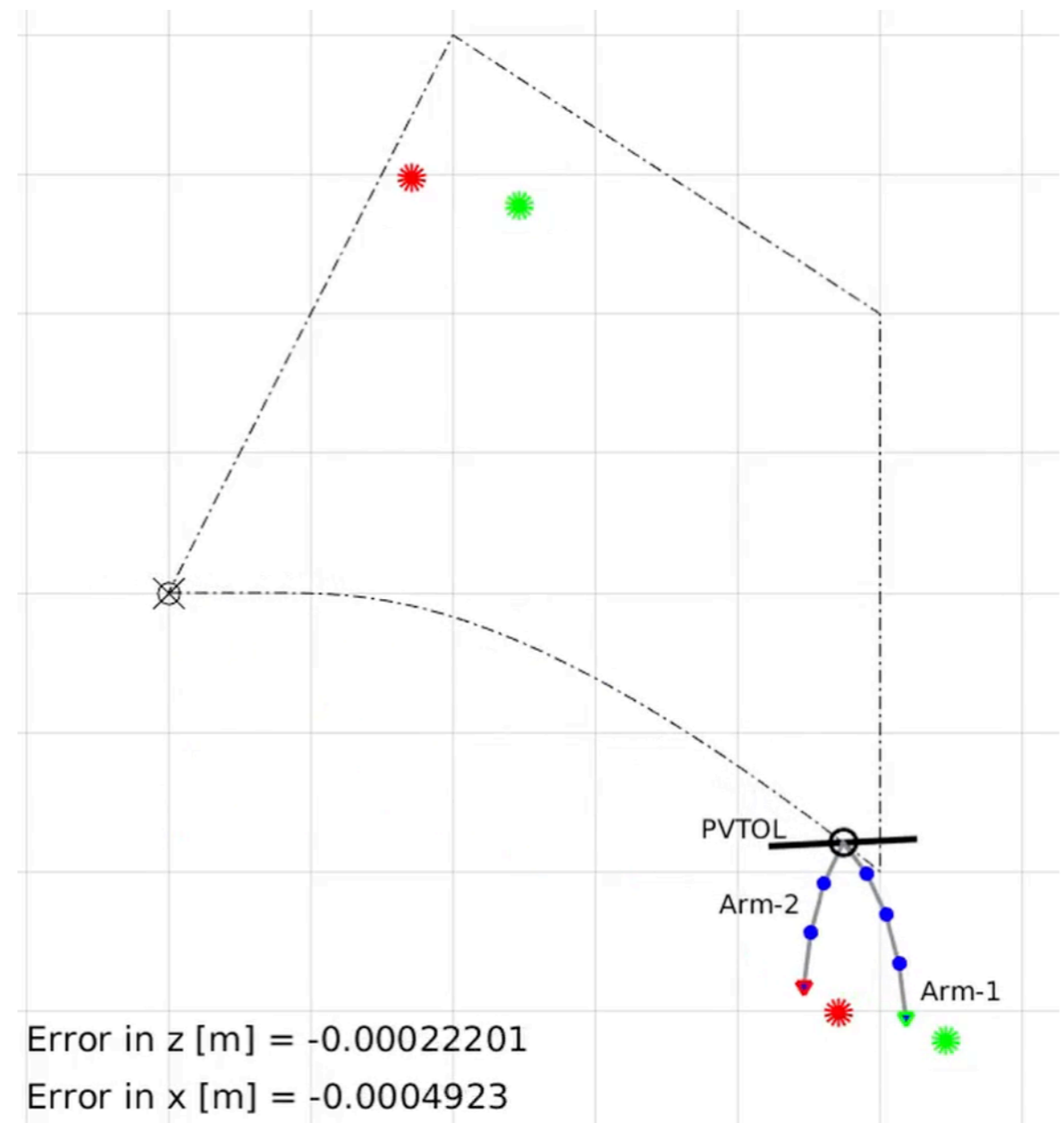
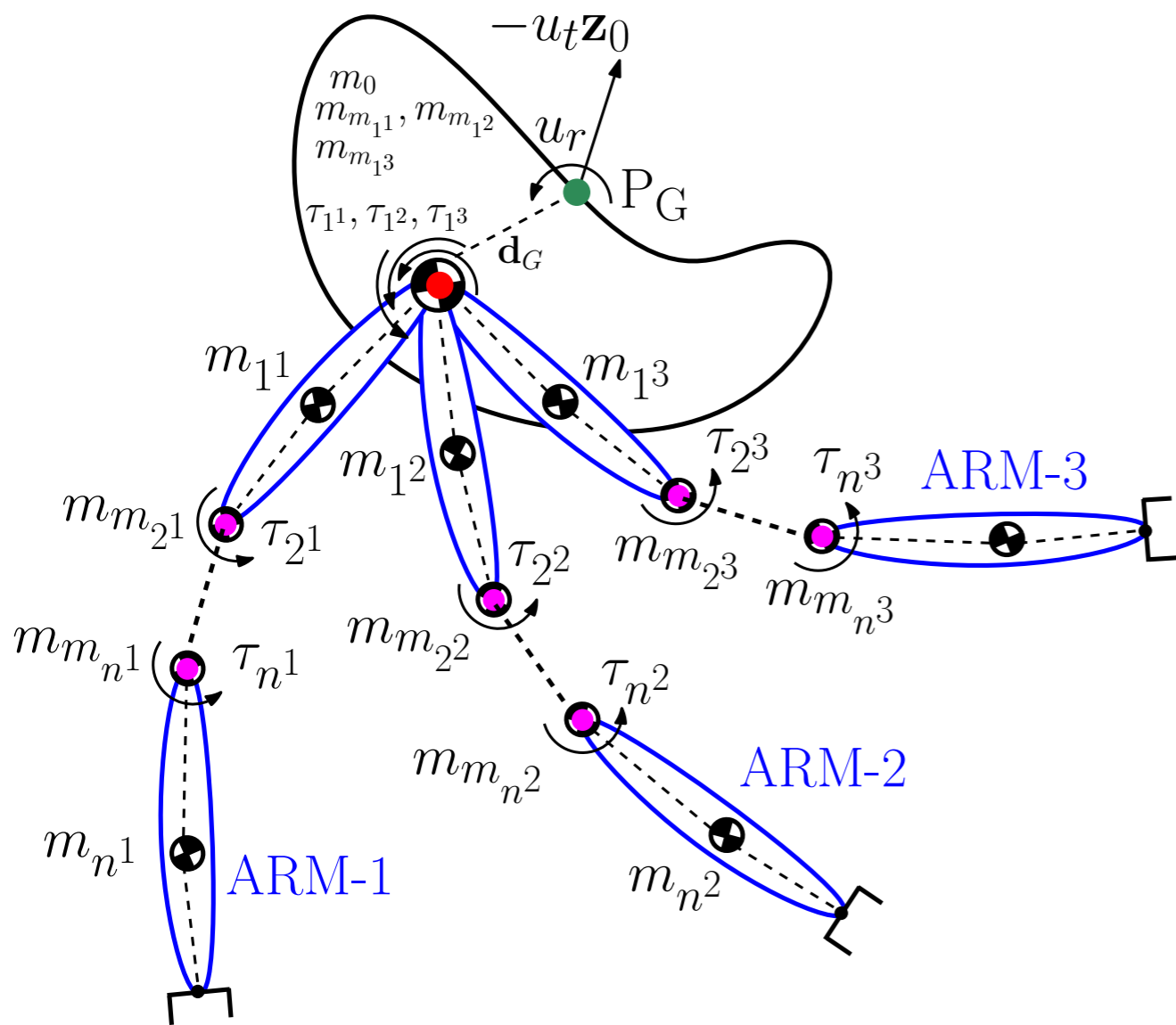
Controller: S^2 -and-attitude controller



<http://homepages.laas.fr/afranchi/robotics/?q=node/293>

2) Protocentric Aerial Manipulators

Protocentric = first joints at the CoM of the first body
 \Rightarrow EE-position are flat outputs



holds also for elastic joints but relative degree grows quadratically!

2) Protocentric Aerial Manipulators (con't)

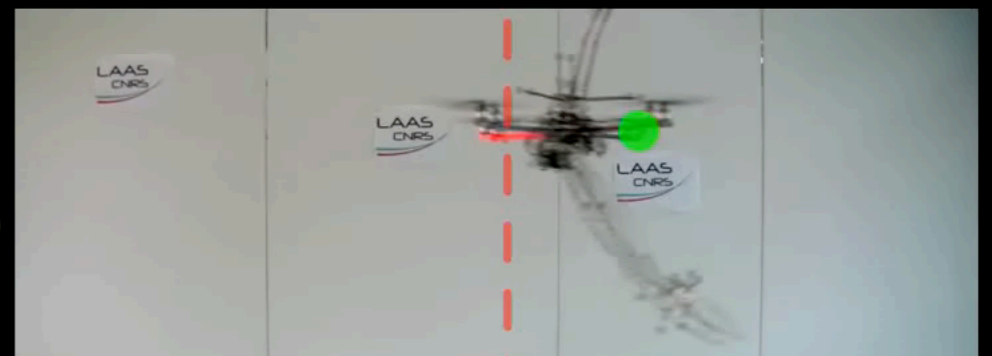
Trajectory (c)

The arm and the quadrotor are requested to oscillate with the same phases:

- * the quadrotor has to oscillate along the x-axis with a period of 3s between -0.5m and +0.5m
- * the 1st and the 2nd link have to oscillate with a period of 3s between $-40^\circ, +40^\circ$ and $-70^\circ, +70^\circ$, respectively.

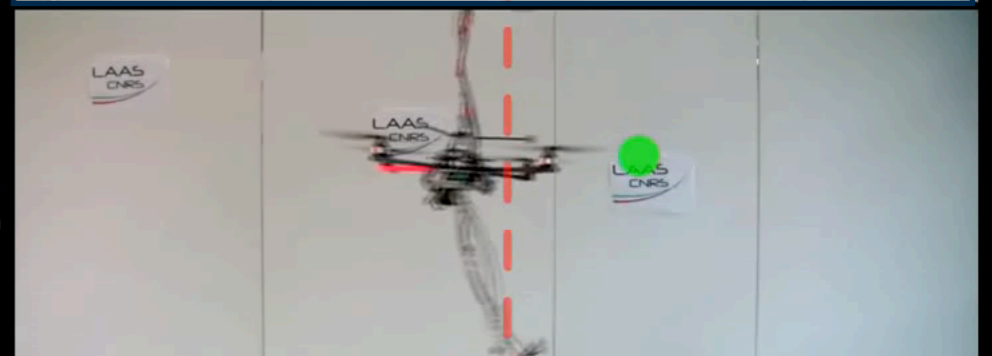
The quadrotor and the arm motions have the same phases.

(1)



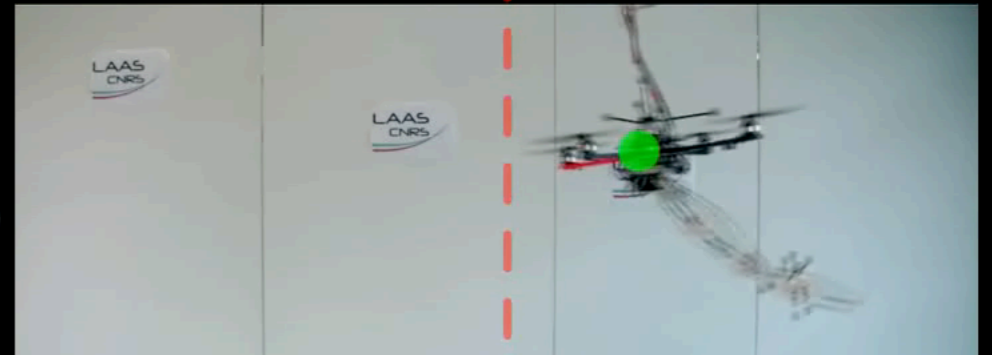
no compensation

(2)



static compensation

(3)



whole-body control

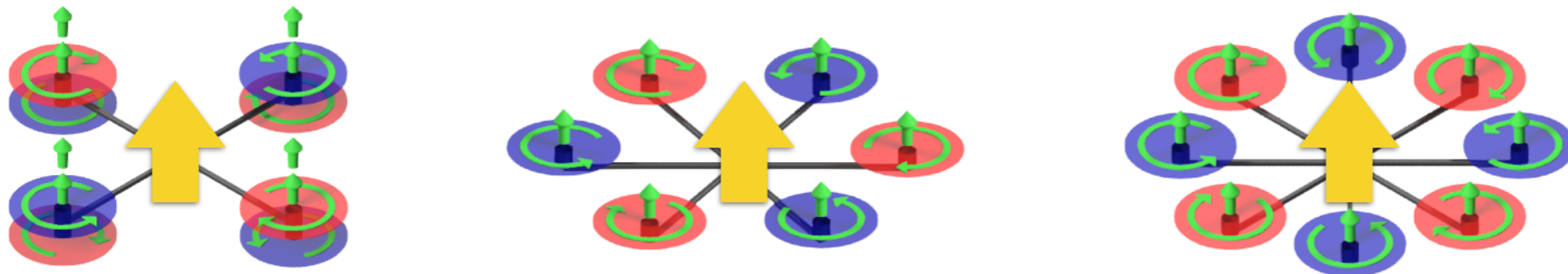
X1

--- Center of the sinusoidal trajectory
● Desired quadrotor position

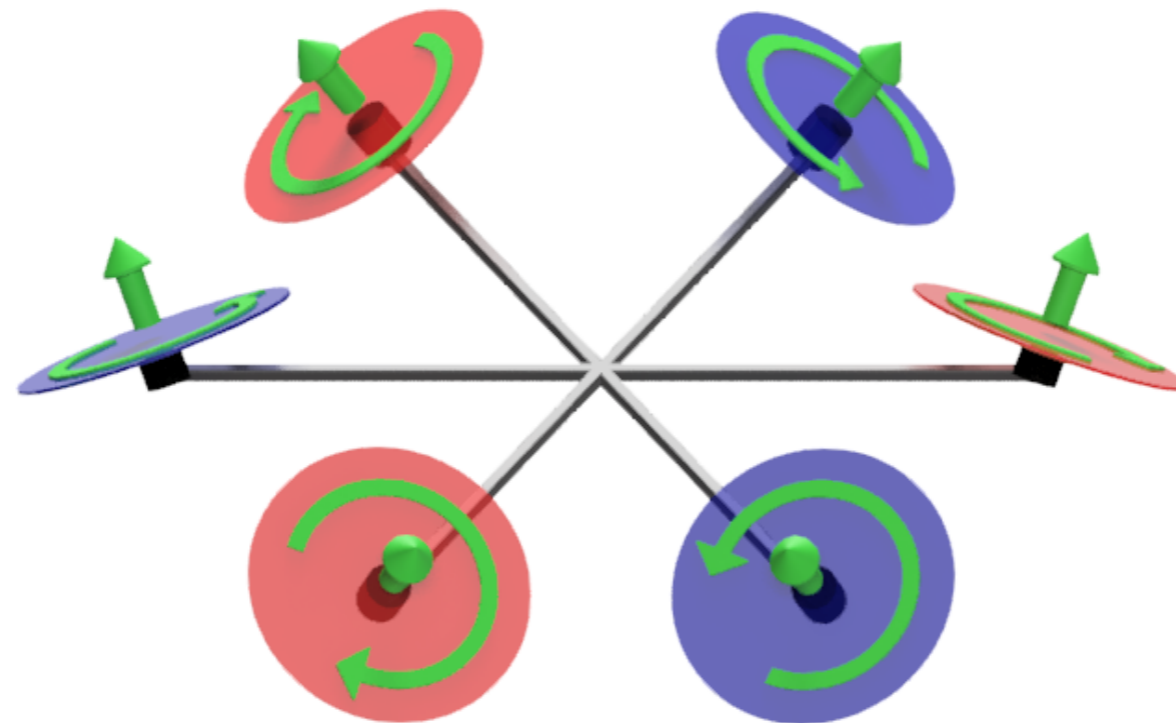
<http://homepages.laas.fr/afranchi/robotics/?q=node/416>

3) The Tilted Hexarotor

Only one total thrust direction



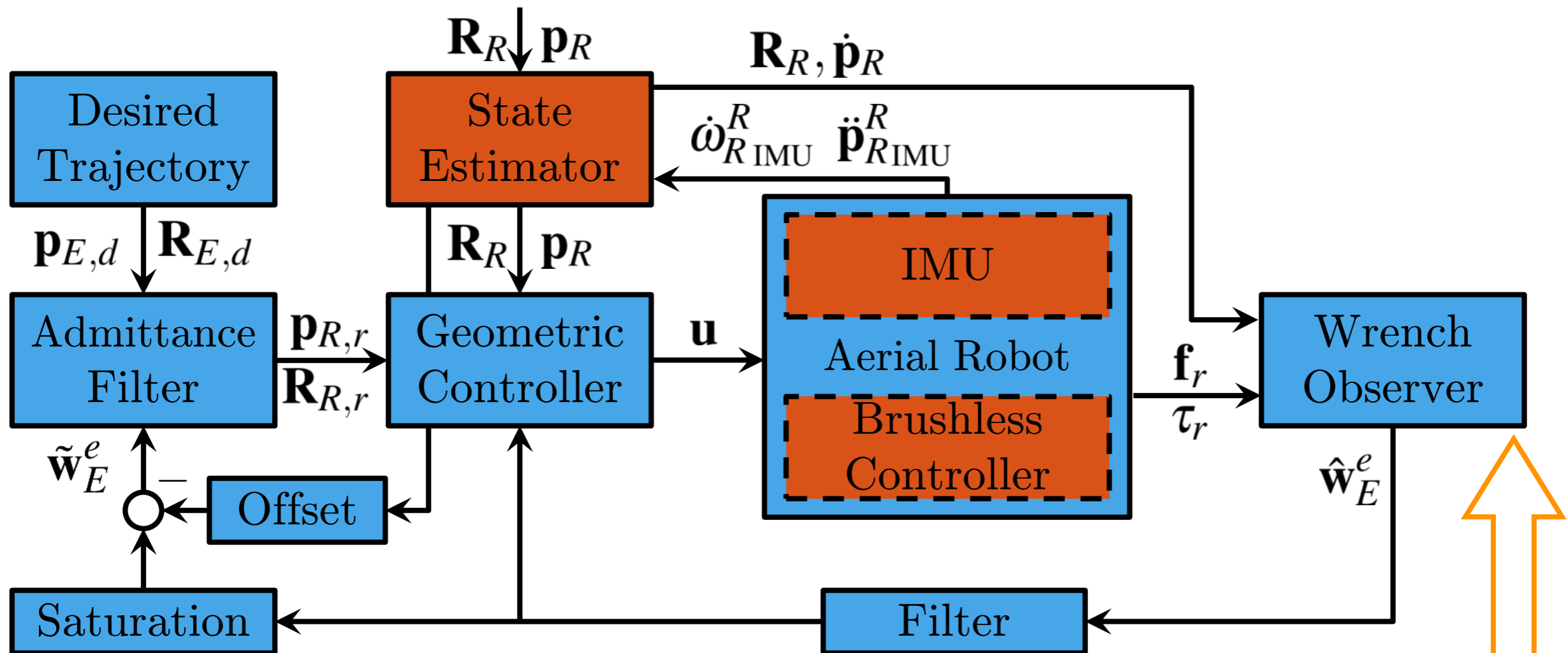
Platforms with **generic** rotor configuration:



Several total thrust directions become possible

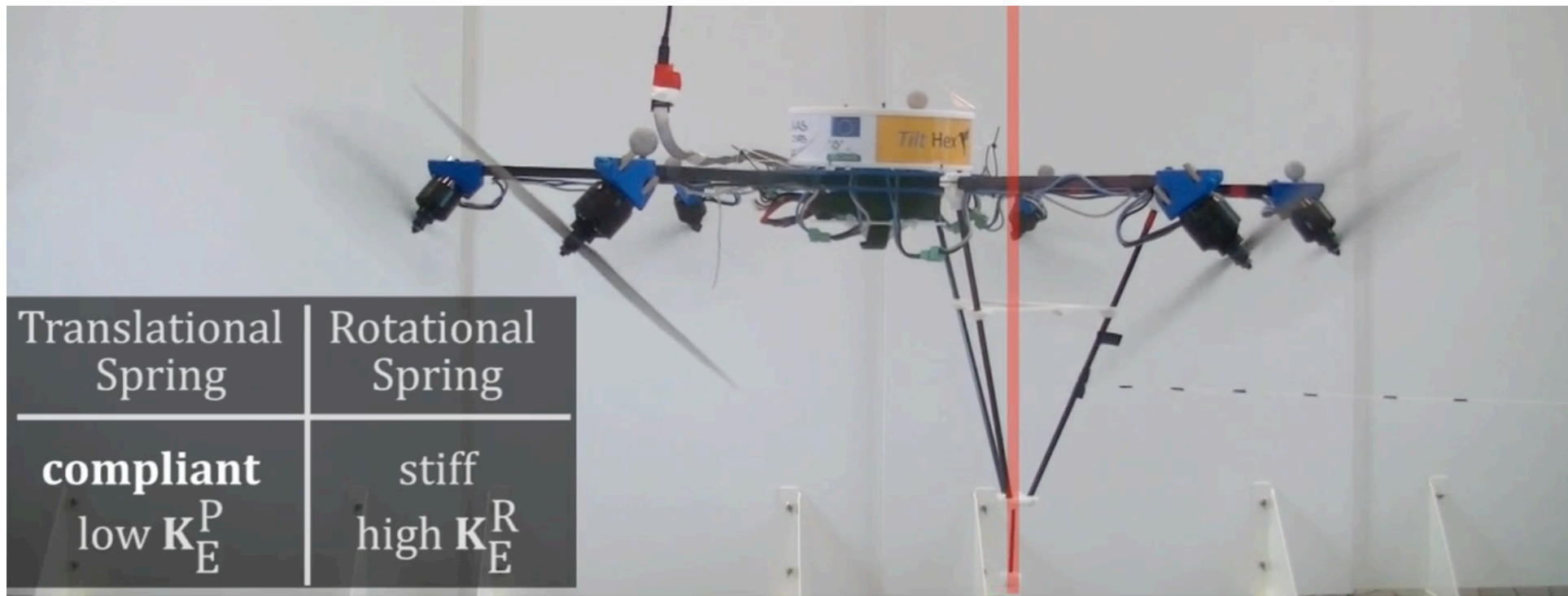
3) The Tilted Hexarotor (con't)

Interaction Control



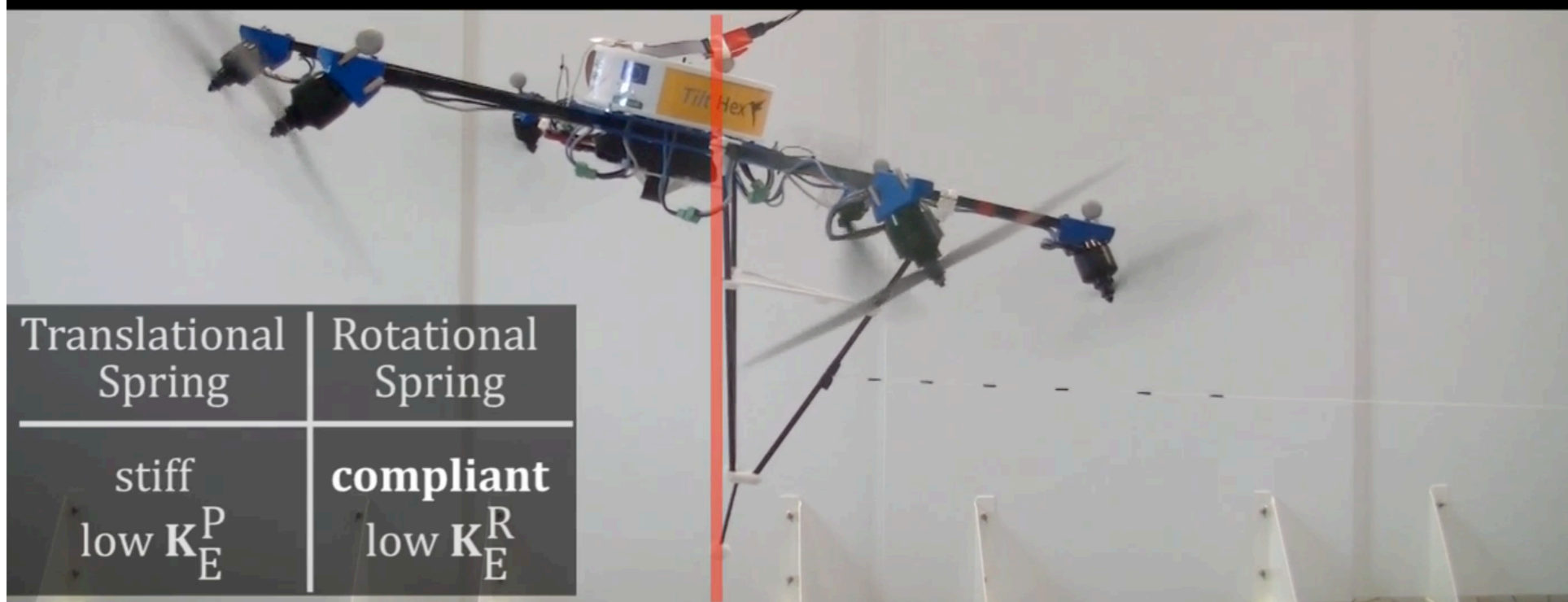
(wrench observer: DeLuca&Mattone 2005)

3) The Tilted Hexarotor (con't)



Translational Spring	Rotational Spring
compliant low K_E^P	stiff high K_E^R

- Low position gain -> only translation
- Low orientation gain-> only rotation



Translational Spring	Rotational Spring
stiff low K_E^P	compliant low K_E^R

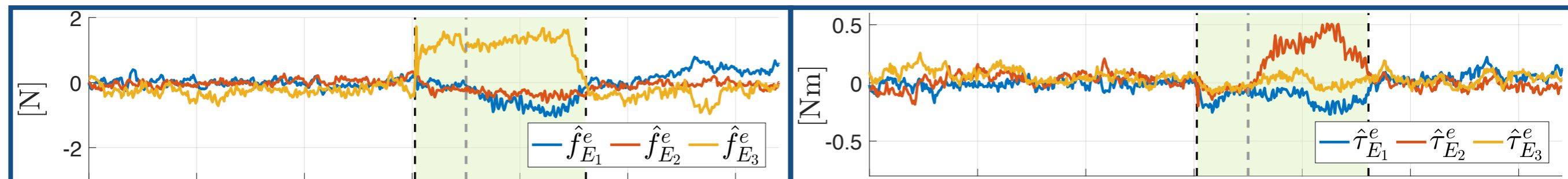
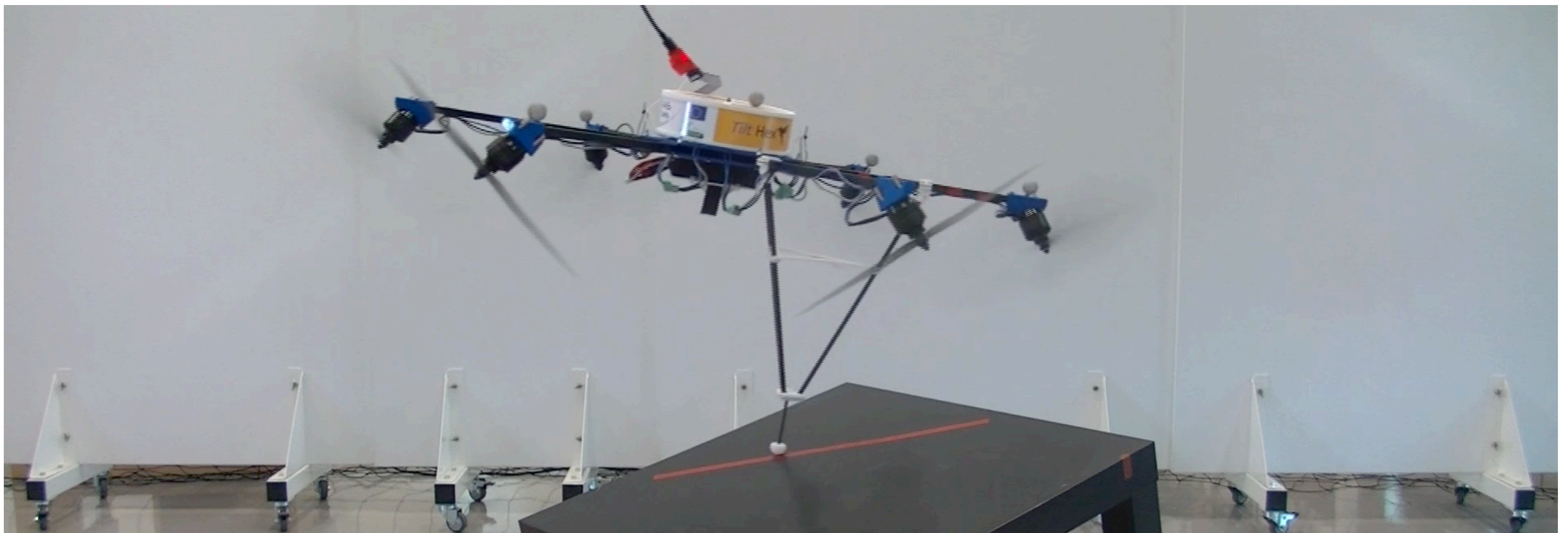
- Aerial vehicle rotates about tool-tip position -> not about center of mass

Independent Position/Orientation Response

3) The Tilted Hexarotor (con't)

Compliance:

the robot is told the surface is horizontal

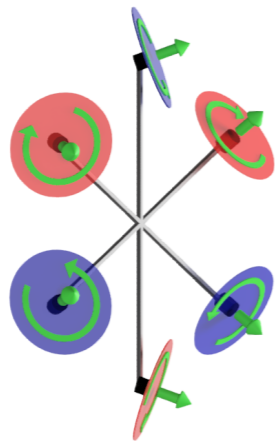
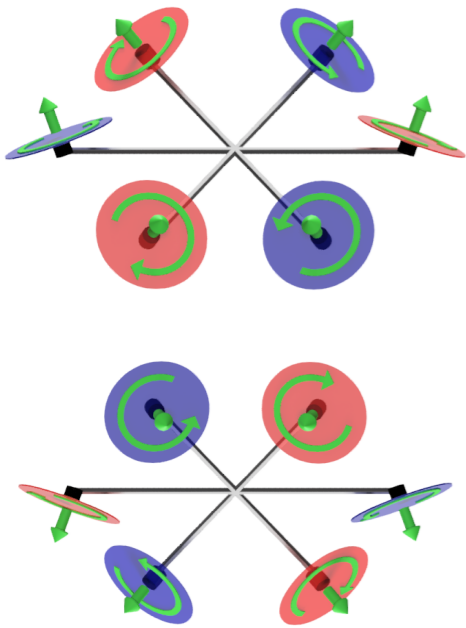


Ext. Force at Tip

Ext. Moment at Tip

4) The Omni+7

Can 'omnidirectionality' stem from unidirectional rotors?



$$\forall \mathbf{w} \in \mathbb{R}^6 \quad \exists \mathbf{u} \geq \mathbf{0} \text{ s.t. } \mathbf{F}\mathbf{u} = \mathbf{w}$$

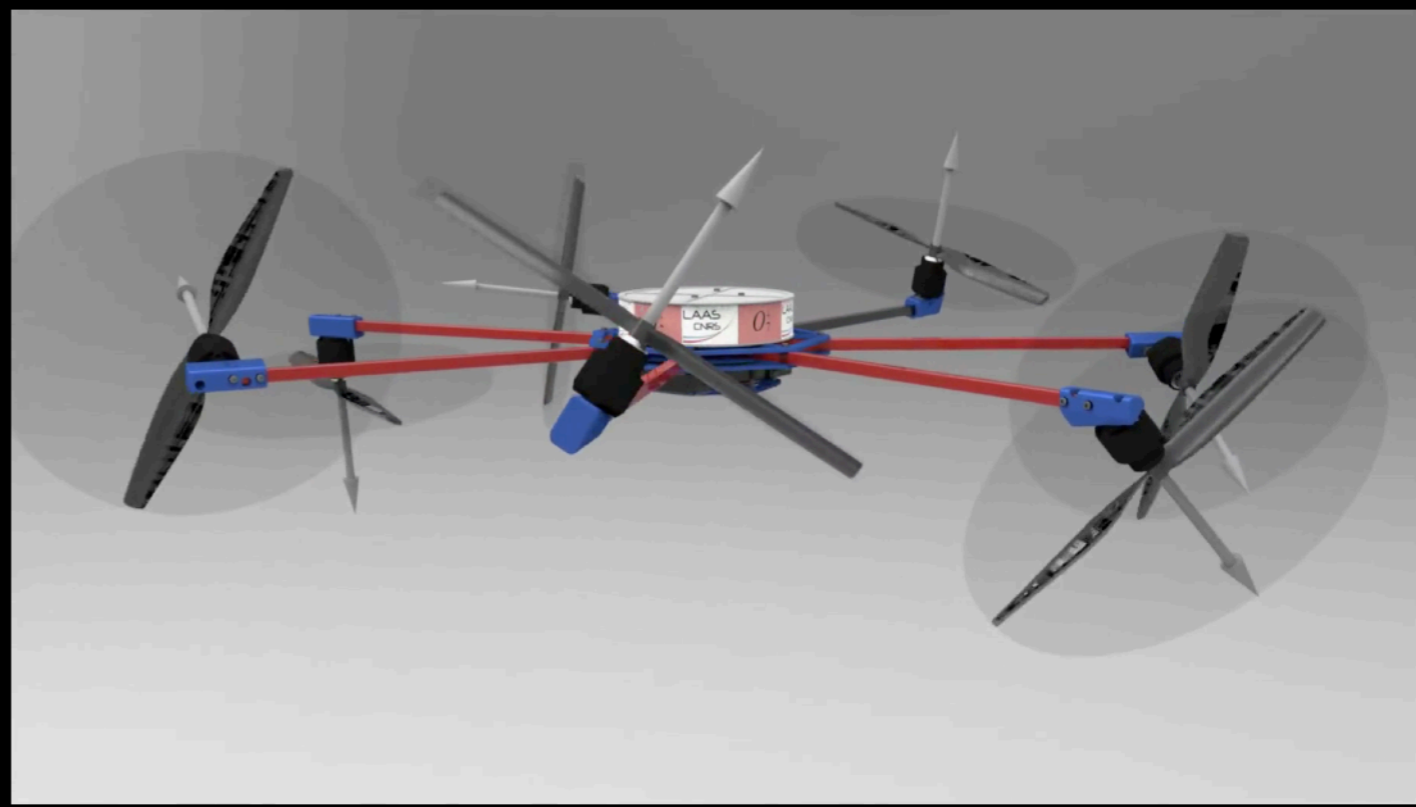
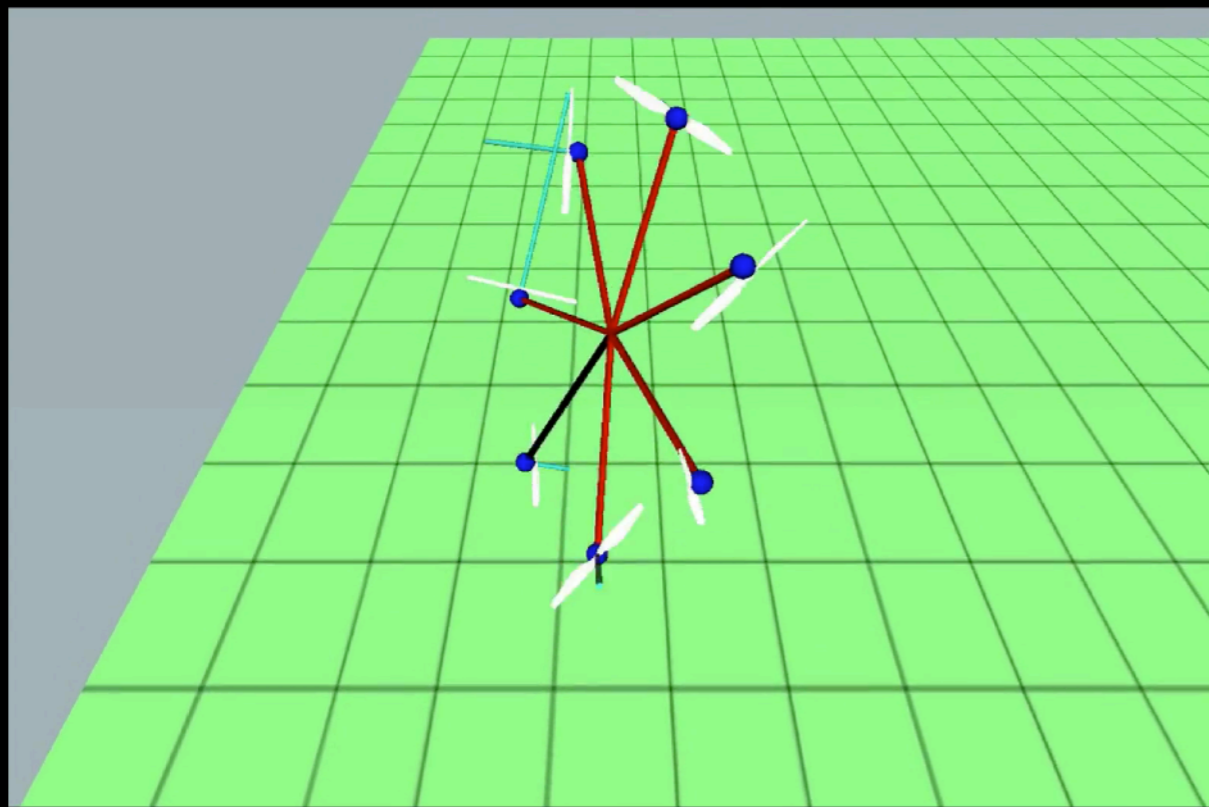


$$\text{rank}(\mathbf{F}) = 6 \quad \text{and} \quad \exists \mathbf{b} > \mathbf{0} \text{ s.t. } \mathbf{F}\mathbf{b} = \mathbf{0}$$

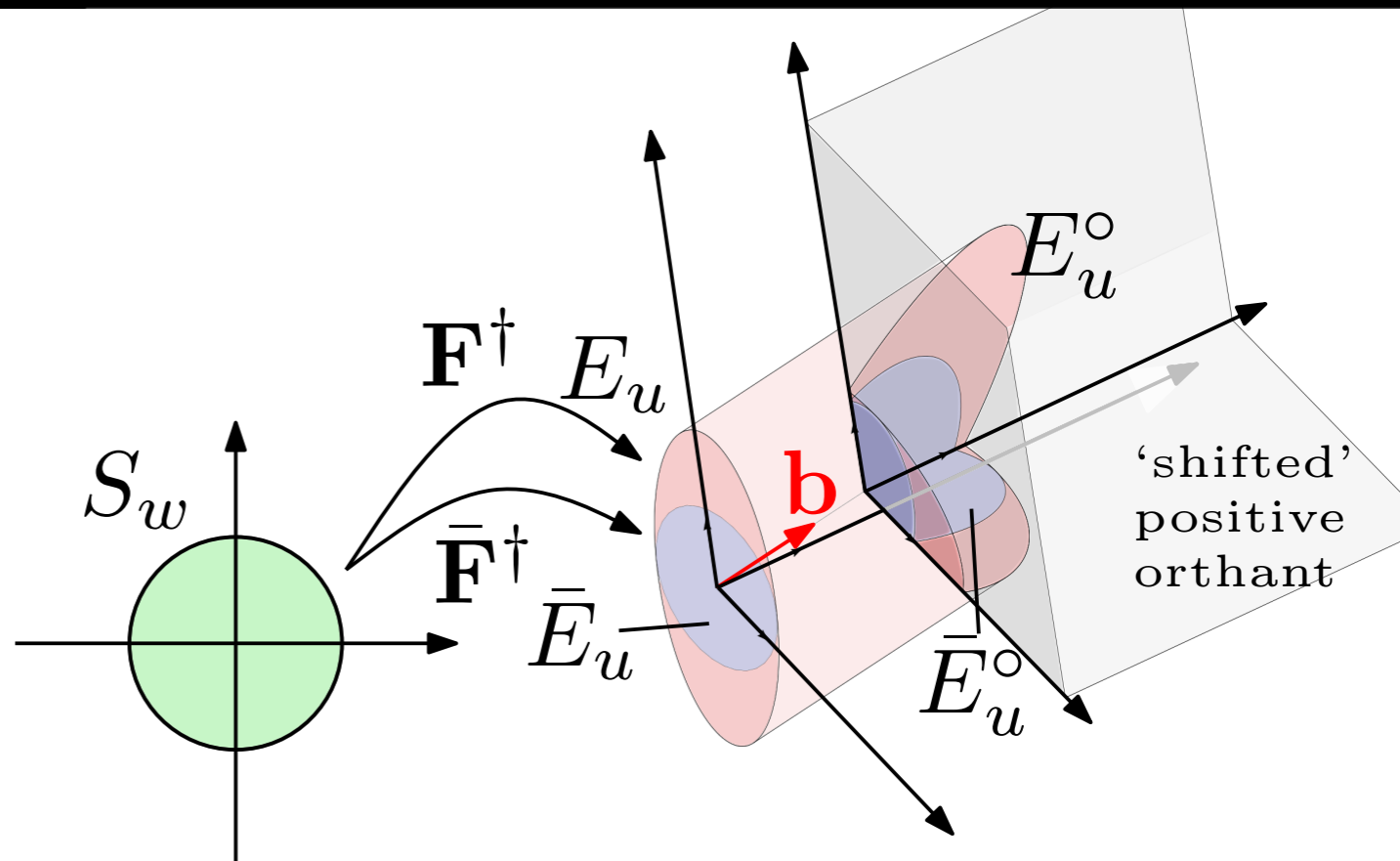
\Rightarrow at least 7 rotors needed

connection with grasping [Bicchi&Kumar 2000]

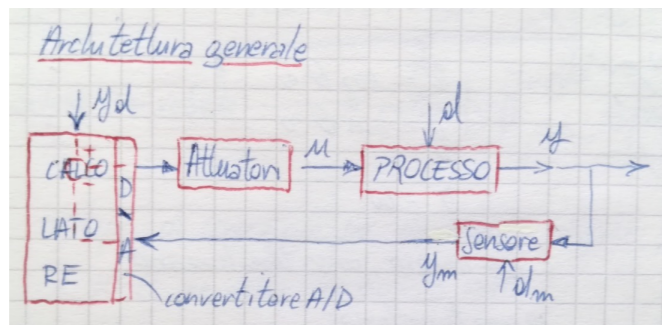
4) The Omni+7 (con't)



optimization of condition number (similar to a manipulability index)



Alessandro's Inception



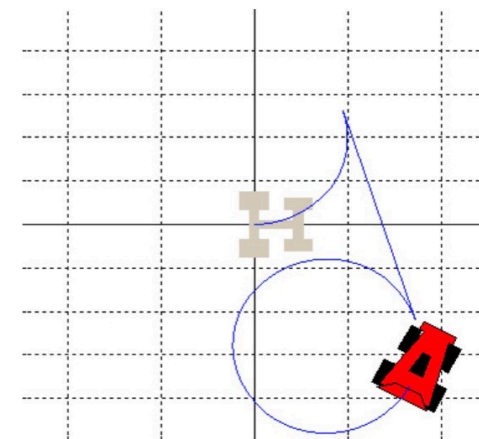
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