Drones Demystified!

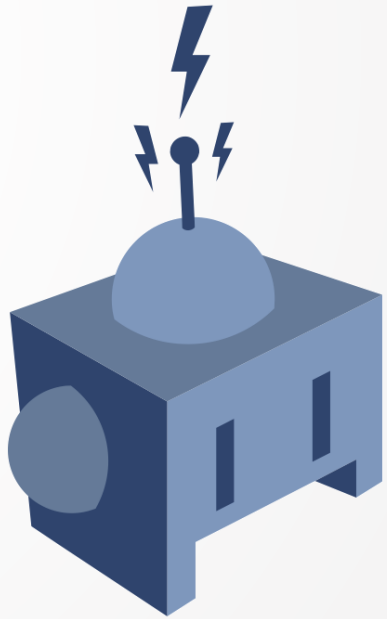
K. Alexis, C. Papachristos, Autonomous Robots Lab, University of Nevada, Reno

A. Tzes, Autonomous Robots & Intelligent Systems Lab, NYU Abu Dhabi

Drones Demystified!

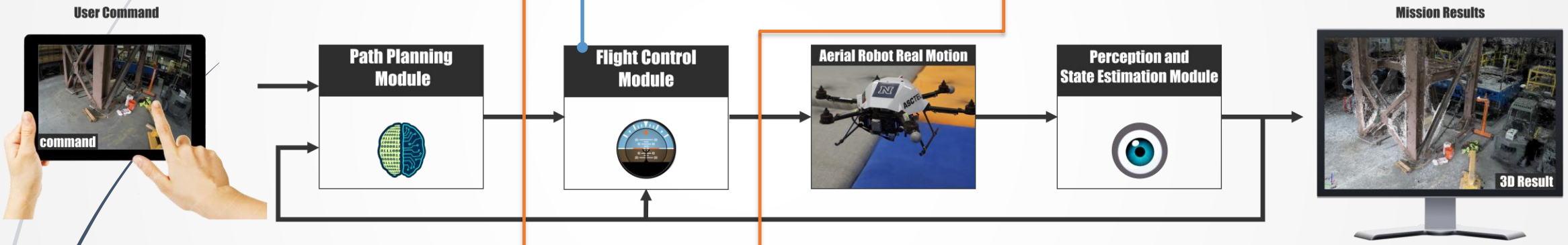
Topic: Flight Controls Introduction

How do I control my motion?



The Aerial Robot Loop

- How to design the flight control of an aerial robot and program its autopilot.



Section 3 of our course

What is it all about?

- **Control theory** is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback.

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- **Control theory** is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback.
- To do that in a systematic way, we should develop a **model-based** approach on control synthesis.

MAV Dynamics

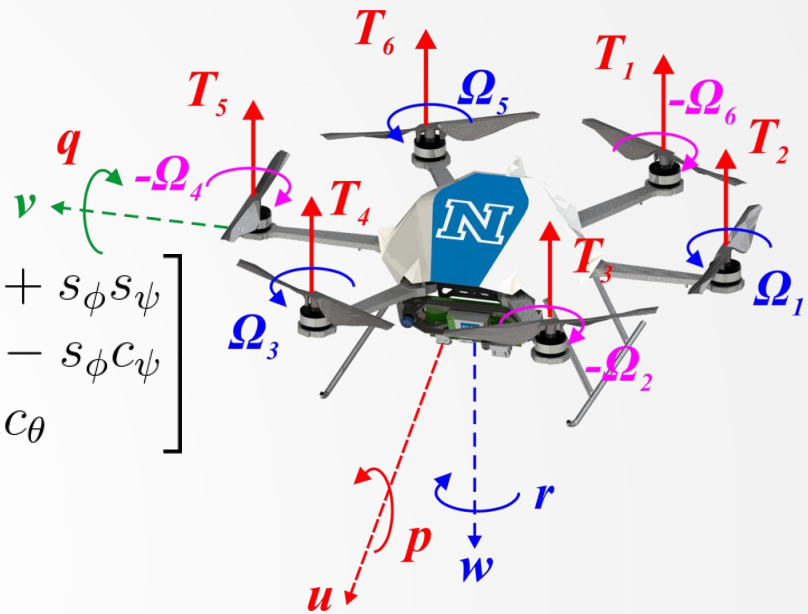
- To append the forces and moments we need to combine their formulation with

$$\begin{bmatrix} \dot{p}_n \\ \dot{p}_e \\ \dot{p}_d \end{bmatrix} = \mathcal{R}_b^v \begin{bmatrix} u \\ v \\ w \end{bmatrix}, \quad \mathcal{R}_b^v = \begin{bmatrix} c_\theta c_\psi & s_\phi s_\theta c_\psi - c_\phi s_\psi & c_\phi s_\theta c_\psi + s_\phi s_\psi \\ c_\theta s_\psi & s_\phi s_\theta s_\psi + c_\phi c_\psi & c_\phi s_\theta s_\psi - s_\phi c_\psi \\ -s_\theta & s_\phi c_\theta & c_\phi c_\theta \end{bmatrix}$$

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = \begin{bmatrix} rv - qw \\ pw - ru \\ qu - pv \end{bmatrix} + \frac{1}{m} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix}$$

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi \tan\theta & \cos\phi \tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi \sec\theta & \cos\phi \sec\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

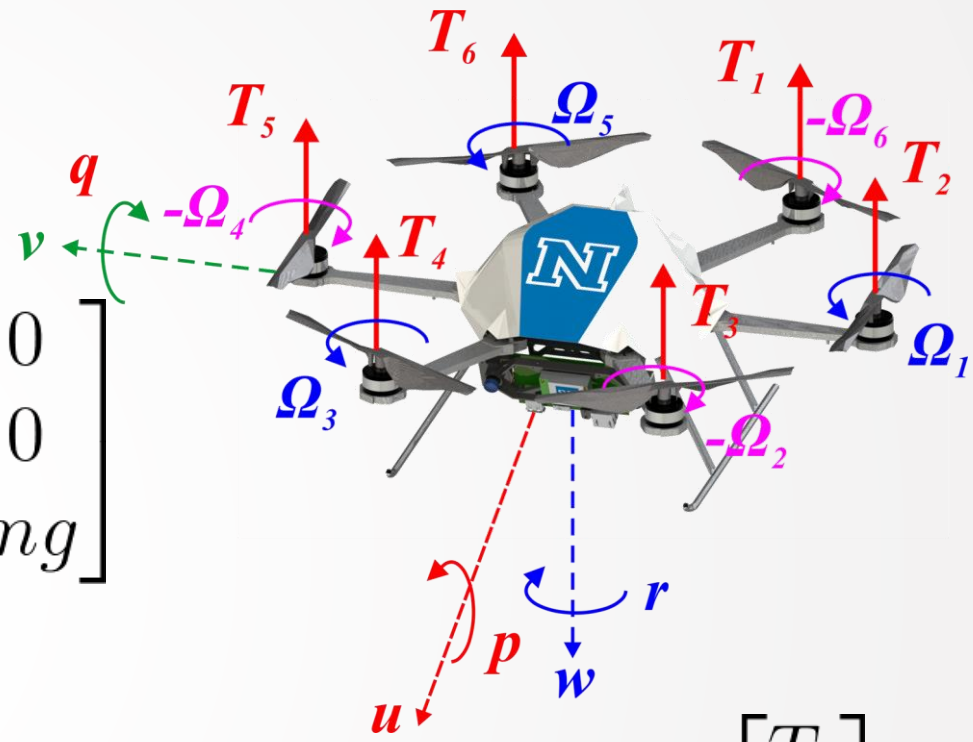
$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} \frac{J_y - J_z}{J_x} qr \\ \frac{J_z - J_x}{J_y} pr \\ \frac{J_x - J_y}{J_z} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} + \begin{bmatrix} \frac{1}{J_x} M_x \\ \frac{1}{J_y} M_y \\ \frac{1}{J_z} M_z \end{bmatrix}$$



MAV Dynamics

- MAV forces in the body frame:

$$\mathbf{f}_b = \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=1}^{6} T_i \end{bmatrix} - \mathcal{R}_v^b \begin{bmatrix} 0 \\ 0 \\ mg \end{bmatrix}$$



- Moments in the body frame:

$$\mathbf{m}_b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} ls_{30} & l & ls_{30} & -ls_{30} & -l & ls_{30} \\ -lc_{60} & 0 & lc_{60} & lc_{60} & 0 & -lc_{60} \\ -k_m & k_m & -k_m & k_m & -k_m & k_m \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix}$$

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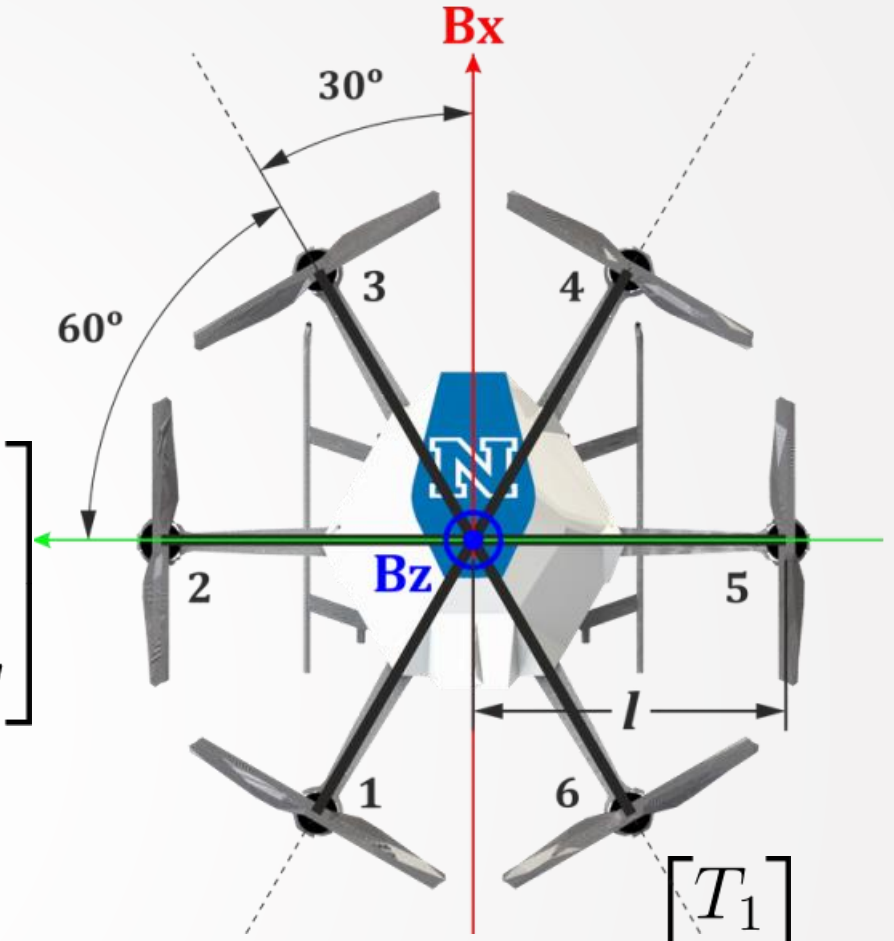

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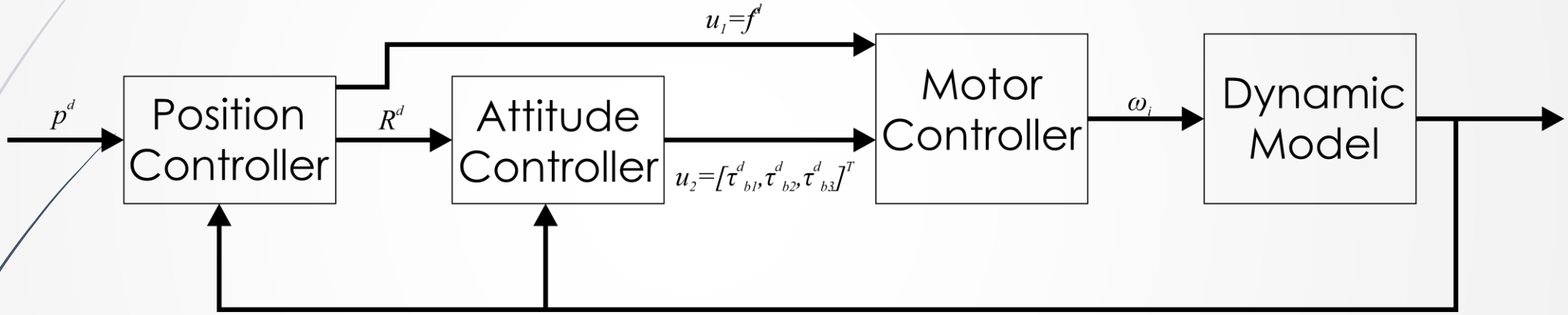
Control System Block Diagram



- Simplified loop

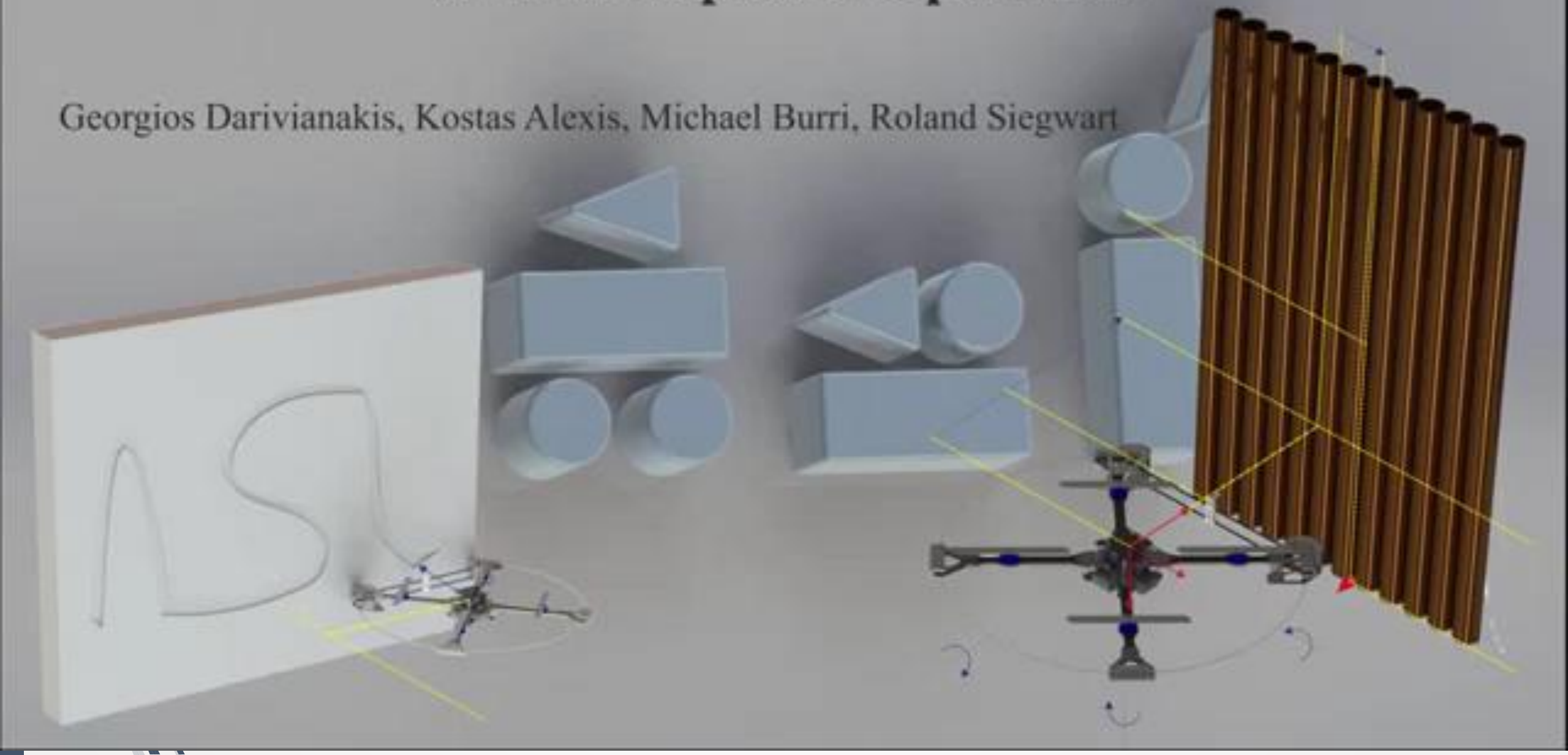
Fast Nonlinear Model Predictive Control for Multicopter Attitude Tracking on SO(3)

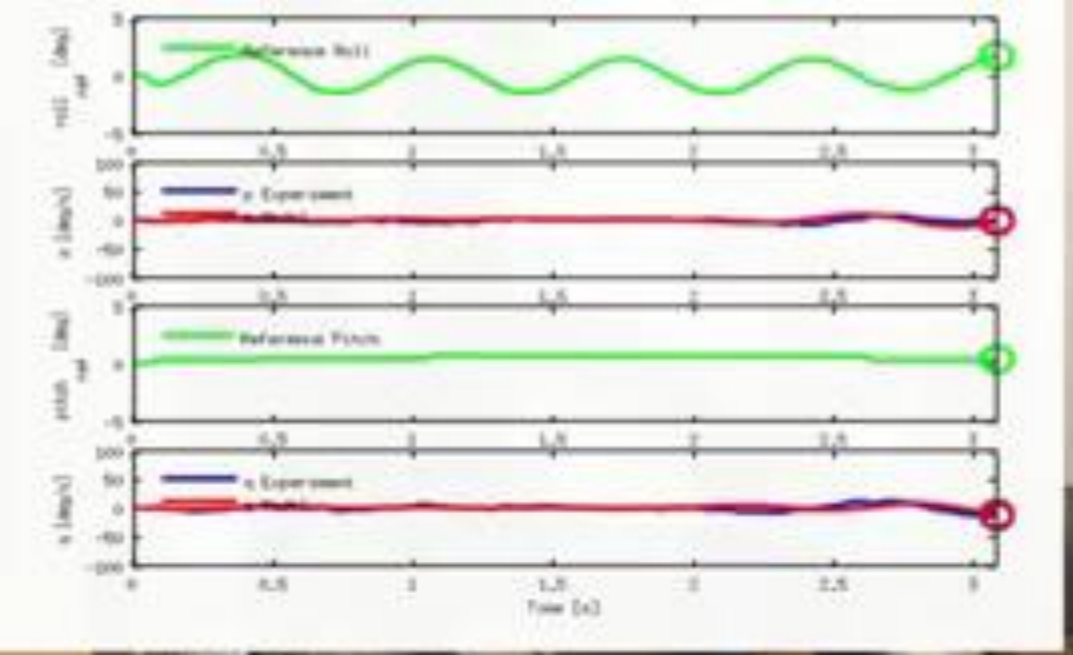
Mina Kamel, Kostas Alexis, Markus Achtelik and Roland Siegwart

Position tracking without one propeller

Hybrid Predictive Control for Aerial Robotic Physical Interaction towards Inspection Operations

Georgios Darivianakis, Kostas Alexis, Michael Burri, Roland Siegwart

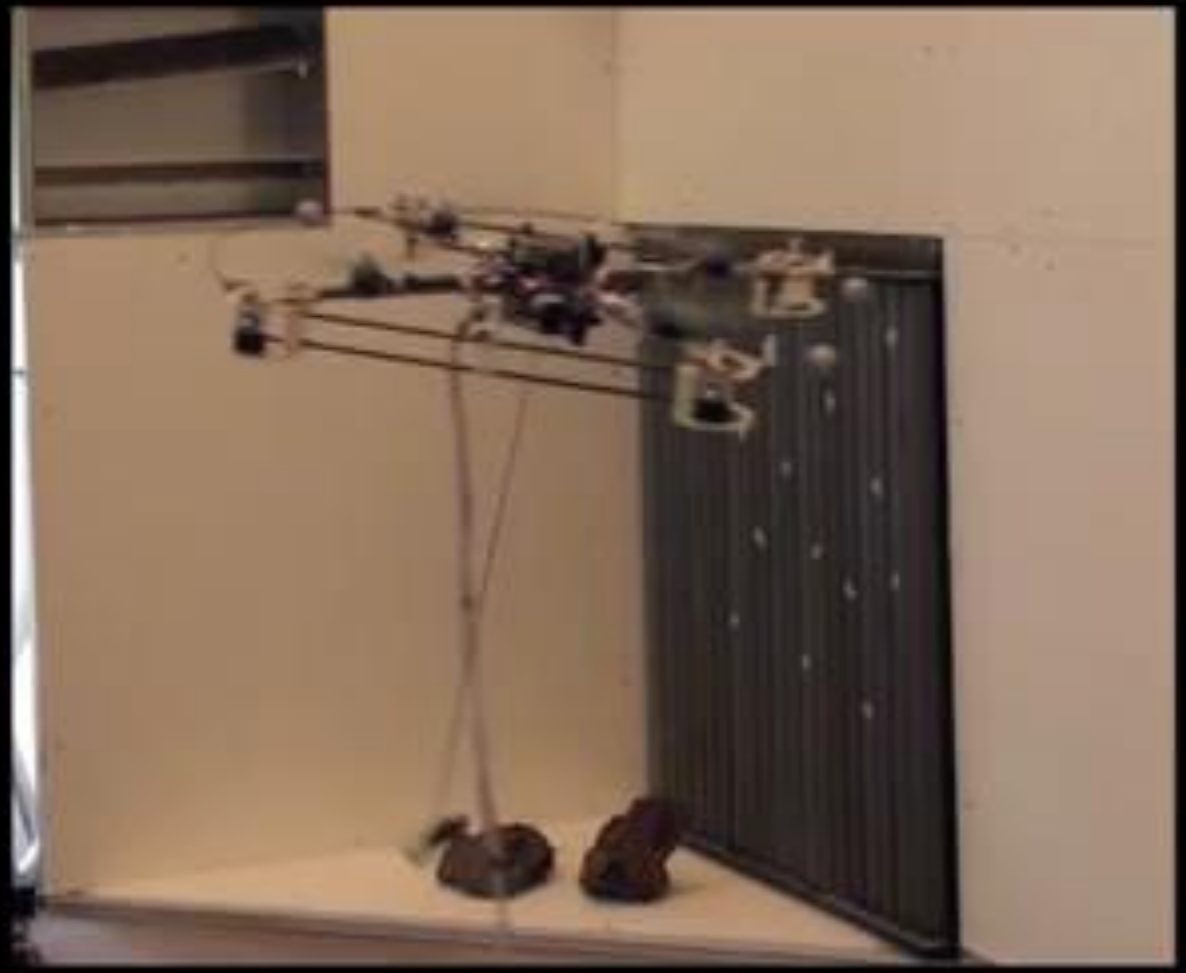



Reference Roll
roll [deg]
p Experiment
p [deg/s]
Reference Pitch
pitch [deg]
q Experiment
q [deg/s]
Time [s]

Test Flight Days #9&#10
(May 5th & 6th 2014)

Aircraft: AtlantikSolar UAV Prototype
Location: Tuggen, Switzerland
Flights performed: 5
Tests: Autopilot Waypoint-following

Slung Load Operations - disturbance of the Load
Test-case using the ASLquad



Vehicle: ASLquad

Type of trajectory: Position hold

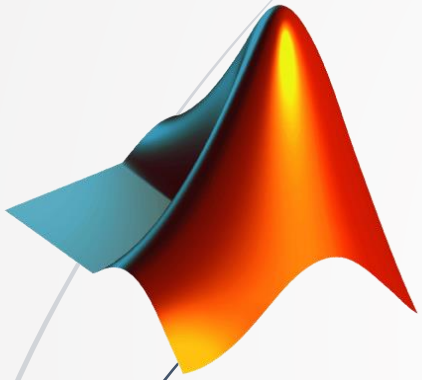
Nature of disturbance: Disturbance introduced from a 0.16kg slung load which is externally disturbed

Corresponding results using the UPAT-TTR unmanned rotorcraft are also presented later on in the same video sequence

AERO WORKS

ETH Manipulator

Code Examples and Tasks

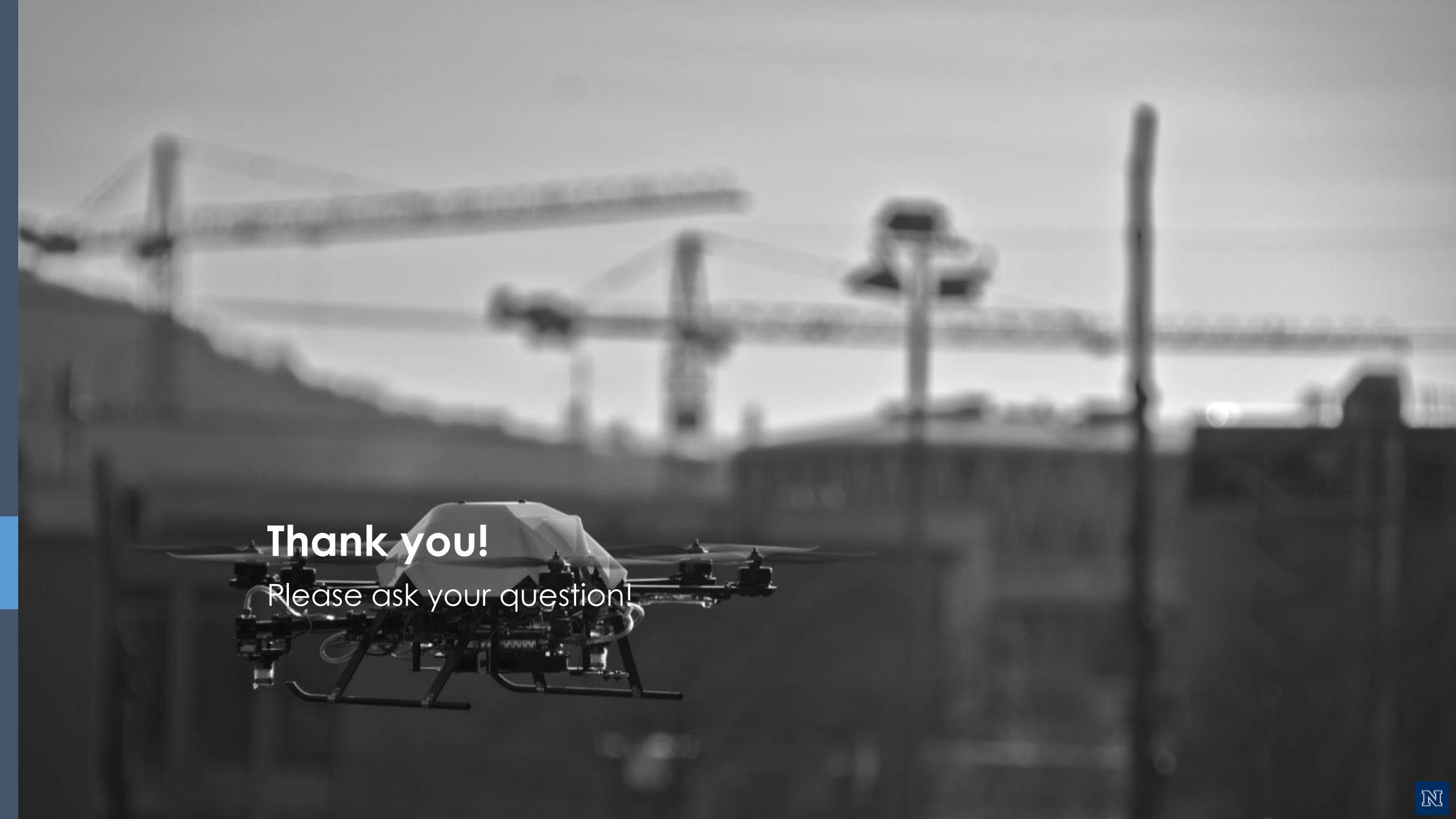


- https://github.com/unr-arl/drones_demystified/tree/master/matlab/control-systems/gain-scheduled-three-loop-aircraft-autopilot
- https://github.com/unr-arl/drones_demystified/tree/master/matlab/control-systems/lqr
- https://github.com/unr-arl/drones_demystified/tree/master/matlab/control-systems/pid-cruise-control
- https://github.com/unr-arl/drones_demystified/tree/master/matlab/control-systems/pid

Find out more

- http://www.autonomousrobotslab.com/pid-control.html
- http://www.autonomousrobotslab.com/lqr-control.html
- http://www.autonomousrobotslab.com/linear-model-predictive-control.html
- http://ctms.engin.umich.edu/CTMS/index.php?example=InvertedPendulum&section=ControlStateSpace

- http://www.autonomousrobotslab.com/literature-and-links1.html



Thank you!

Please ask your question!