Safety and reliability of autonomous flying machines Flying Machine Arena

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Flying Machine Arena

http://www.idsc.ethz.ch/Research_DAndrea/FMA/participants

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Distributed Flight Array

http://www.idsc.ethz.ch/Research_DAndrea/DFA
The Flying Machine Arena

- A 10x10x10m space for autonomous flight

- Main components:
  - Flying vehicles (quadrocopters)
  - Motion capture system
  - Wireless communication system
  - Algorithms
Quadrocopter dynamic model

\[ \ddot{x} = \frac{1}{m} \mathbf{R} \begin{bmatrix} 0 \\ 0 \\ f_1 + f_2 + f_3 + f_4 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} \]

\[ \dot{\mathbf{R}} = \mathbf{R} \begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix} \]

\[ \mathbf{I}^B \dot{\omega}^B = - \sum_{i=1}^{4} \mathbf{I}^P \omega_i^P - [\omega^B \times] \left( \mathbf{I}^B \omega^B + \sum_{i=1}^{4} \mathbf{I}^P \left( \omega^B + \omega_i^P \right) \right) + \tau_{res} \]
Without control
Closed loop
Recovering from large disturbances

Dario Brescianini, Markus Hehn

- Large pitch/roll torques
  - Small yaw torque
- Control attitude through angular velocity
- Prioritize tilt over yaw

\[
\ddot{x} = \frac{1}{m} \mathbf{R} \begin{bmatrix} 0 & 0 \\ f_1 + f_2 + f_3 + f_4 & 0 \end{bmatrix} - \begin{bmatrix} 0 \\ g \end{bmatrix}
\]

\[
\dot{\mathbf{R}} = \mathbf{R} \begin{bmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{bmatrix}
\]

\[
\mathbf{I}^B \dot{\omega}^B = -\sum_{i=1}^{4} \mathbf{I}^P \dot{\omega}^P_i - [\omega^B \times] \left( \mathbf{I}^B \omega^B + \sum_{i=1}^{4} \mathbf{I}^P (\omega^B + \omega^P_i) \right) + \tau_{res}
\]
Recovering from large disturbances

Dario Brescianini, Markus Hehn
“Typical” multicopters

How many propellers do you really need?

E-Volo, Amazon Prime Air
MK Hexa XL, DJI Phantom
System modelling – 2 propellers

- Can *not* directly affect roll rate
- Have to exploit attitude coupling

\[
I^B \dot{\omega}^B + \sum_{i=1}^{4} I^P \dot{\omega}^P_i + [\omega^B \times] \left( I^B \omega^B + \sum_{i=1}^{4} I^P (\omega^B + \omega^P_i) \right) = \tau_{\text{res}}
\]
Flying with three propellers

\[ \omega^B = (0, 5.7, 18.9) \text{rad/s} \]

2.05N

2.05N

1.02N

\[ m g = 4.9 \text{N} \]
Flying with two propellers

$\omega^B = (0, 0, 30.1) \text{rad/s}$

$mg = 4.9 \text{N}$
Flying with one propeller

\[ \omega^B = (14.7, 0, 33) \text{ rad/s} \]

\[ m g = 4.9 \text{ N} \]
Extension: quadrocopter failsafe
Extension: no motion capture
Demonstrations at lunch